EGYPTIAN CIVIL AVIATION AUTHORITY

REPORT OF INVESTIGATION OF ACCIDENT

EgyptAir Flight 990

October 31, 1999

Boeing 767-300ER SU-GAP

Atlantic Ocean – 60 Miles Southeast of Nantucket Island

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ACCIDENT REPORT -- EGYPTAIR FLIGHT 990

ABBREVIATIONS

A/P	Autopilot
ACK	Nantucket, Massachusetts
AD	Airworthiness Directive
ADC	Air Data Computer
AGL	Above Ground Module
AMIC	Area Manager in Charge
ARSR	Air Route Surveillance Radar
ARTCC	Air Route Traffic Control Center
ASOS	Automated Surface Observation System
ASR	Airport Surveillance Radar
ATC	Air Traffic Control
CAI	Cairo International Airport
CAS	Computed Airspeed
CDR	Continuous Data Recording
CFD	Computational Fluid Dynamic
CFO	Command First Officer
CFR	Code of Federal Regulation
CVR	Cockpit Voice Recorder
CWS	Control wheel Steering
DARC	Direct Access Radar Channel
EADI	Electronic Attitude Director Indicators
EAS	Elevator Autopilot System
ECAA	Egyptian Civil Aviation Authority
EDT	Eastern Day Time
EEC	Electronic Engine Control
EHSI	Electronic Horizontal Indication
EPR	Engine Pressure Ratio
EQA	Engineering Quality Analysis
EST	Eastern Standard Time
EWR	Newark International Airport
F/O	First Officer
FAA	Federal Aviation Administration
FBI	Federal Bureau Of Investigation
FCC	Flight Control Computers
FDR	Flight Data Recorder
GIB	Gibbsbora, New York
HRG	Hurghada Egypt
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
IVS	Instantaneous Vertical Speed

JFK	John F. Kennedy International Airport
LAX	Los Angles International Airport
LVDT	Linear Variable Differential Transducer
MH	Manifold Housing
MMO	Maximum Operating Speed
MPD	Maintenance Planning Document
NOAA	National Oceanographic and Atmospheric Administration
NOR	North Truro, Massachusetts
NTAP	National Track Analysis Program
NTSB	National Transportation Safety Board
OCA	Oceana, Virginia
PCA	Power Control Actuator
QRH	Quick Reference Handbook
RAT	Ram Air Turbine
RFO	Relief First Officer
RIV	Riverhead, New York
SAM	Stabilizer Aileron Lockout Module
SDR	Service Difficulty Report
SEM	Scanning Electron Microscope
STCM	Stabilizer Control Module
SV	Solenoid Valve
T/O	Take Off
TED	Trailing Edge Down
TR	Thrust Reverse
TUP	Trailing Edge UP
USAF	Unite State Air Force

SUMMARY

At approximately 0150 Eastern Standard Time EST on October 31, 1999, a Boeing 767-300 ER, registration SU-GAP, operated by EgyptAir as Flight 990 from New York, New York to Cairo, Egypt crashed into the Atlantic Ocean approximately 60 miles south of Nantucket, Massachusetts. The flight departed John F. Kennedy airport at about 0122 EST as a scheduled international flight under the provisions of Egyptian Civil Aviation Regulations Part 121, and Title 14 of the United States Code of Federal Regulations Part 129. There were no survivors among the 203 passengers, 10 flight attendants, and 4 crewmembers.

Egyptian officials were notified of the accident approximately an hour and 40 minutes later when the American Embassy in Cairo informed the Egyptian Civil Aviation Authority (ECAA) in Cairo which, in turn, informed Captain Shaker Kelada, General Manager Flight Operation Control, and through him the officials of EgyptAir. Thereafter, A.V.M. A. Kato, Chairman of the ECAA conferred with James Hall, Chairman of the United States National Transportation Safety Board NTSB regarding the investigation of the accident. By fax message dated October 31, General Kato wrote that "the ECAA agrees to authorize the NTSB to conduct the investigation regarding the accident of EgyptAir flight number 990".

The ECAA authorization was in accordance with Paragraph 5.3 of Annex 13 to the Convention on International Civil Aviation (the "Chicago Convention"). This paragraph provides that:

> When the location of the accident or incident cannot definitely be established as being in the territory of any State, the State of Registry shall institute and conduct any necessary investigation of the accident or serious incident. However, it may delegate the whole or any part of the investigation to another State by mutual arrangement and consent.

On November 1, 1999, the NTSB accepted the ECAA's delegation of the investigation and advised that it "look[ed] forward to meeting with your representatives and working with them on the investigation." Pursuant to section 5.3 of Annex 13, it was anticipated that the investigation would be conducted as a partnership between equals. However, it soon became apparent that the NTSB leadership did not regard the Egyptian delegation as an equal partner and shared its processes, if at all, on a selective and seemingly random basis. Often the Egyptian delegation read about the NTSB's views in the press without prior communication.

Between early November 1999 and late August 2000, ECAA and EgyptAir investigators, engineers, and experts (the "Egyptian team") maintained facilities in Washington, D.C. and at the NTSB to participate in the investigation of the Flight 990 accident. Although the Egyptian investigators were, to one degree or another, involved in aspects of the investigation and were assigned to the various NTSB working groups, their input was often ignored and their questions were often left unanswered. Nevertheless, the Egyptian investigators had access to data collected by the NTSB, along with additional information and analyses developed independently by Egyptian experts and by other experts retained by the Egyptian Team.

The detailed reports of various aspects of the investigation of this accident were prepared by the NTSB with the assistance of the Egyptian investigators and set forth certain information in connection with Flight 990 as to which there is no disagreement.[1] In the view of Egyptian investigators, however, other reports and analyses are incomplete because they are based upon either erroneous or misleading data. In these areas, which are discussed in this report, Egyptian investigators have attempted to address gaps in the investigation using the information available from the NTSB and from the Boeing Company, the manufacturer of the airplane.

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[1] Much of the factual information contained in this report is taken directly from the reports in the NTSB public docket. The most recent index of the NTSB's docket is attached as Appendix A-7

The Egyptian Delegation and the ECAA has had difficulty analyzing all of the issues of this accident because certain tests and information that would assist in analyzing this accident are not available, and the NTSB has refused to conduct any further investigation. In spite of this refusal, however, it is possible to arrive at certain conclusions:

1. The Relief First Officer (RFO) did not deliberately dive the airplane into the ocean. Nowhere in the 1665 pages of the NTSB's docket or in the 18 months of investigative effort is there any evidence to support the so-called "deliberate act theory." In fact, the record contains specific evidence refuting such a theory, including an expert evaluation by Dr. Adel Fouad, a highly experienced psychiatrist.
2. There is evidence pointing to a mechanical defect in the elevator control system of the accident. The best evidence of this is the shearing of certain rivets in two of the right elevator bellcranks and the shearing of an internal pin in a power control actuator (PCA) that was attached to the right elevator. Although this evidence, combined with certain data from the Flight Data Recorder (FDR), points to a mechanical cause for the accident, reaching a definitive conclusion at this point is not possible because of the complexity of the elevator system, the lack of reliable data from Boeing, and the limitations of the simulation and ground tests conducted after the accident. Additional evidence of relevant Boeing 767 elevator malfunctions in incidents involving Aero Mexico (February 2000), Gulf Air and American Airlines (March, 2001). There were also two incidents on a United Airlines airplane in 1994 and 1996.
3. Investigators cannot rule out the possibility that the RFO may have taken emergency action to avoid a collision with an unknown object. Although plausible, this theory cannot be tested because the United States has refused to release certain radar calibration and test data that are necessary to evaluate various unidentified radar returns in the vicinity of Flight 990.

The ECAA remains committed to determining the cause of the crash of Flight 990 and will continue to examine the evidence and conduct relevant tests.

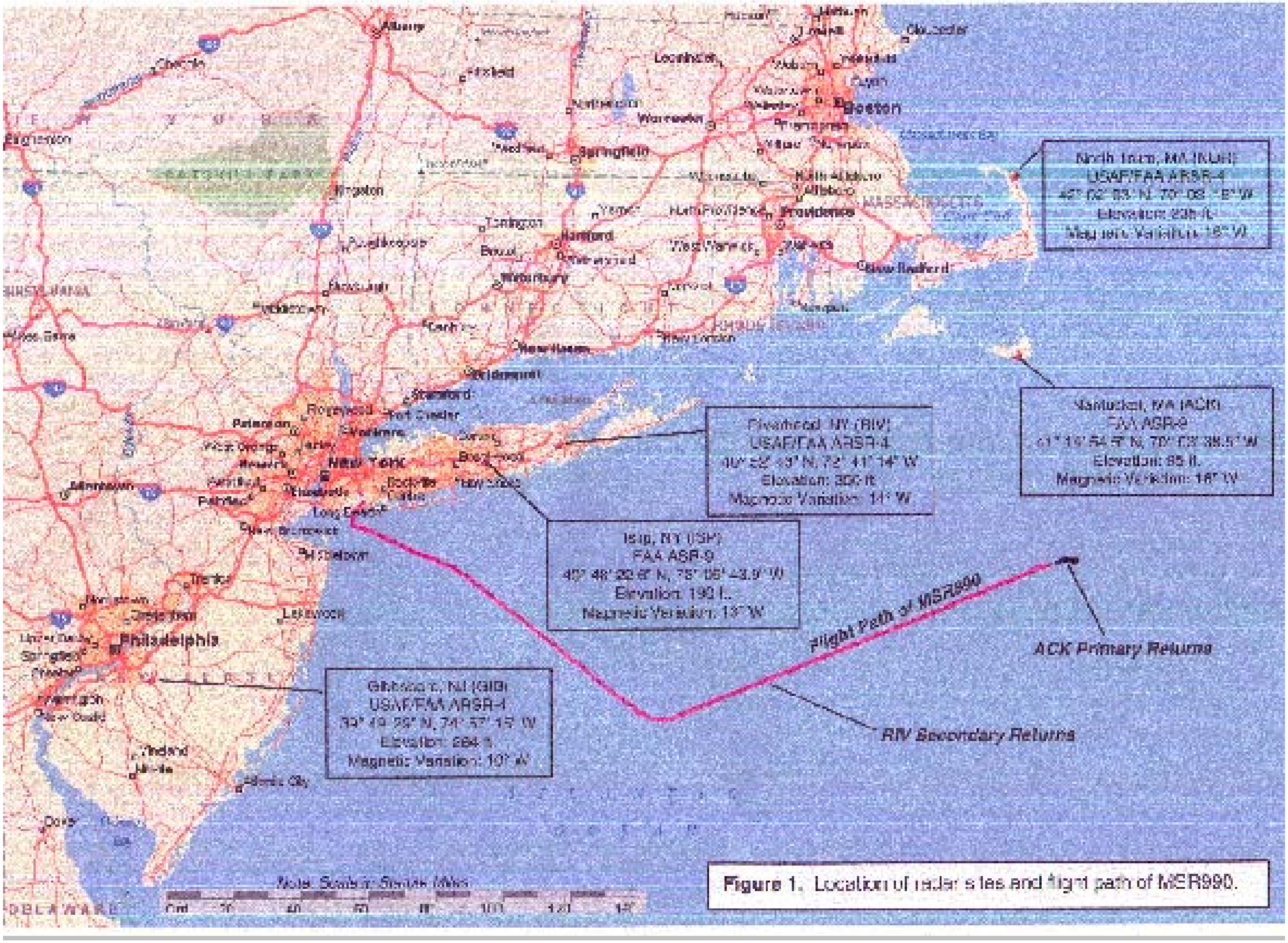

Figure 1. Location of radar sites and flight path of MSR990.

1.0 FACTUAL INFORMATION

1.1 History of the Flight

On October 31, 1999, about 0150,[2] EgyptAir Flight 990, a Boeing 767-366ER, SU-GAP, crashed into the Atlantic Ocean approximately 60 miles southeast of Nantucket, Massachusetts. Flight 990 was operating under the provisions of Egyptian Civil Aviation Regulations, Part 121, and United States Title 14 Code of Federal Regulations (CFR) Part 129 as a scheduled international flight from John F. Kennedy Airport (JFK), New York, New York, to Cairo International Airport (CAI) in Cairo, Egypt. The path of Flight 990 is shown in Figure 1. The flight departed JFK about 0122 with 4 flight crewmembers, 10 flight attendants, and 203 passengers on board. There were no survivors. A small amount of floating debris was recovered from the ocean during the morning of October 31, 1999. Additional debris was recovered from a depth of approximately 220 feet during salvage operations in December 1999 and March 2000. Visual meteorological conditions prevailed for the flight, which was operated on an instrument flight rules (IFR) flight plan.

Flight 990 was part of a scheduled trip sequence from Cairo to Los Angeles (LAX) with an intermediate stop in New York (Flight 989) and the return to Cairo, again with an intermediate stop in New York (Flight 990). The accident began the trip in Cairo on October 30, 1999 as Flight 989 and landed at Newark International Airport (EWR) in northern New Jersey because of poor weather at JFK. After a crew change, Flight 989 departed for LAX. Later on October 30, the airplane was designated Flight 990 and departed LAX for JFK. The departure of Flight 990 from LAX was delayed so that tires seven and eight on the main landing gear could be replaced. Flight 990 arrived at its gate at JFK at 0010 EDT on October 31, 1999.

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[2] All times relating to the accident are Eastern Standard Time ("EST") unless otherwise indicated. Certain times prior to the accident are Eastern Daylight Time ("EDT") because the time changed during the overnight period from October 30 to October 31. All times are based on a 24-hour clock.

At JFK, EgyptAir contracted with Alitalia for dispatch services. On October 31, 1999, the Alitalia dispatcher prepared the flight folder, including load data, wind, and weather. Because all EgyptAir flights across the North Atlantic are ETOPS, the dispatcher also included NOTAM data for the airports of intended use and airports listed as equal time points on the flight plan. All of this information was provided to the EgyptAir dispatcher who was responsible for dispatching the flight.

The planned route for Flight 990 on October 31, 1999 was JFK … SHIP … LACKS … DOVEY … NATZ … STG … CAI. The time enroute at 33,000 feet was forecast to be 10:00 hours via NAT "Z" at a cruise speed of .80 Mach. The flight plan distance was 5,077 nautical miles, and the IFR alternate airport was Hurghada, Egypt (HRG).

EgyptAir 990 pushed back from its gate at JFK at about 0100 and taxied to runway 22R. The flight was cleared for takeoff at approximately 0119. At 0124, Flight 990 was manually handed off from New York TRACON to New York Center. A manual handoff was required because the JFK tower had failed to reenter the EgyptAir 990 flight plan after flushing the system during overnight computer maintenance. The flight plan was entered into the system by New York Center. At 0126:35, Flight 990 contacted New York Center and continued climbing to FL 230. At 0135:52, EgyptAir 990 was cleared to its requested cruising altitude of FL 330 and direct to the DOVEY intersection.[3] An oceanic clearance was issued to the flight at 0141:52 and acknowledged by the crew at 0142:13. The New York Center controller requested that Flight 990 change frequencies at 0147:18. The Captain acknowledged the frequency change at 0147:40 and transmitted "EgyptAir ah, nine nine zero heavy, good morning."

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[3] The planned route of flight was generally southeast of JFK to the LACKS intersection and then generally northeast to DOVEY. This route avoided entering any military Warning Areas. At 0135:52, while Flight 990 was in climb to 33,000 feet and on course to LACKS, the controller cleared the flight "direct DOVEY." Following this clearance, which was acknowledged by the Flight 990 crew, the airplane turned northeast, crossing Warning Areas 105 and 506 enroute to DOVEY. The accident site is approximately 135 nautical miles from DOVEY.

At 0148:03, Captain Ahmed El Habashy stated to RFO Gamil El Batouty, who was occupying the First Officer's right seat, "Excuse me Jimmy, while I take a quick trip to the toilet." This was followed by the sound of an electric seat moving. First Officer El Batouty was part of the relief crew on this flight and had changed places with the Command First Officer (CFO), Adel Anwar, who occupied the right seat during the departure. This change was made without objection from the Captain El Habashy. It was unclear how many people were in the cockpit either before Captain El Habashy left or thereafter because several different voices were identified on the CVR. There is no specific evidence that any of the speakers left the cockpit at any time.

At 0148:18.55, the CVR recorded a sound similar to the cockpit door opening while Captain Habashy was on his way to the toilet, followed at 0148:30.69 by a sound on the CVR of three syllables of a non-Arabic word or words. According to the CVR group report, the four Arabic speaking group members believe that they heard words similar to "control it." The sounds thought to be "control it" and other statements recorded by the CVR during the accident sequence were subjected to sound spectrum analysis by the NTSB. It was determined that the sounds contained human speech characteristics, but were not of sufficient clarity to determine positively who said it. A comparison of the characteristics of these sounds with known examples of inter-cockpit speech from earlier in the flight failed to produce a match. Although the NTSB advised that it intended to engage an outside expert to perform further analysis on the CVR, no expert was retained and no additional spectrum analysis was performed. In addition, no analysis of unidentified non-speech sounds was undertaken.

At 0148:34.80, there was another sound of a "click" and a "thump," followed at 0148:39.92 by the statement of the RFO, "I rely on God." This utterance was "faintly heard." Between 0148:49.30 and 0149:30.16, the CVR recorded six events that were described as "thumps" or "faint thumps." At 0149:36, the FDR showed a rapid, 0.7

degree movement of the left elevator.[4] Seven seconds later, at 0149:45, the autopilot was disengaged, followed at 0149:48.42 by the RFO's comment, "I rely on God." The absence of an aural warning indicated that this disconnection was likely made through the switches on the control column. At the time that the autopilot was disconnected, the was heading approximately 080 at a pressure altitude of 33,000 feet.

The moment the autopilot was disconnected, both the right and left elevators moved trailing edge down ("TED"). However, the movement of the elevators was irregular. The left elevator went down from a constant 0.70º to 0.53º trailing edge up ("TEU"). The right elevator went from 0.35º TEU, downward to 0.18º TED.

In the 8 seconds following the disengagement of the autopilot, both elevators moved slightly toward a TED position. At 0149:54, the right elevator moved sharply toward a pronounced TED position. This action was followed at 0149:55 by an identical movement of the left elevator. Between 0149:55 and 0150:04, the TED positions of the two elevators moved erratically, fluctuating between 3º and 4º TED. At 0150:08, both elevators moved to approximately 5.00º TED in 4 seconds. Over the course of the elevator movements described above, the FDR showed the deflection of the right and left elevators to be at least 0.5º different.

After the second utterance of "I rely on God" at 0149:48.42, the RFO repeated this phrase eight times until 0150:06 when the Captain, who had returned to the cockpit, said, "What's happening? What's happening?" At 0150:06.57 and then again at 0150:08.48, the RFO repeated, "I rely on God." The Captain questioned at 0150:08.5 "What's happening?" and again, at 0150:15.10, "What's happening, Gamil? What's happening?" There was no conversation by anyone in the cockpit indicating a physical

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[4] Although this movement was described as "rapid" in the NTSB's FDR Factual report, which was reviewed and agreed upon by the Egyptian team, this description was deleted from the FDR Factual report placed in the docket.

struggle, nor were there any comments suggesting that the First Officer or anyone else was manipulating the flight controls improperly or in a manner that the Captain disputed.

The initial deflection of the elevators immediately after the autopilot disconnected resulted in a decrease in the pitch attitude. The loss of altitude and the increase of the airplane's speed triggered a Master Caution at 0149:58.63 and a Master Warning~~,~~ at 0150:08.20 respectively. Another Master Caution tone was recorded at 0150:19.40. With the sharp deflection in the elevators, the downward pitch continued to increase, finally reaching approximately 40° nose down. Despite the rapid pitch downward, from the time of the autopilot disconnect until the end of the recording, there was an effort, confirmed by the FDR data, to maintain the airplane in a stable, wings level attitude. The FDR recorded only about 10° of bank in either direction. The roll was always corrected to wing level condition.

At approximately 0150:08.98, the right and left elevators began to move in a trailing edge up ("TEU") This elevator movement started just after the Captain first asked, "What's happening?" at 01:50:06.37 and reached a neutral deflection at 0150:20.98. Movement of the elevators in a TEU direction stopped the increasing pitch and, began reducing the pitch angle at 0150:15. As control of the airplane was being regained, there was no indication of a struggle or of any action that the Captain disapproved.

At approximately 0150:20.98, when the airplane was at 21,000 feet pressure altitude with an airspeed of about 0.99 Mach, the FDR showed a split between the right and left elevators, and the outboard and inboard ailerons showed behavior that was not consistent with the way they should behave with respect to the Boeing 767 aileron system design.

Although the elevators began to move TEU when the was at 23,000 feet pressure altitude, the descent continued to approximately 16,000 feet, at which point the FDR ceased recording. During the dive, the reached an estimated airspeed of 0.99 Mach and experienced "g" forces ranging from +0.98 to -0.227.

The FDR recorded that a low engine oil pressure illuminated at 150:09 and at 150:11. The Engine Start Lever was changed from "Engine Run" to "Cutoff" at 0150:21 and 0150:22 for the right and left engines respectively. Shortly thereafter, at 0150:26 the speed brake was deployed. At 0150:28.7, the Captain ordered, "Shut the engines," to which the RFO responded at 0150:29.6, "It's shut." Between 0150:31.30 and 0150:36.90, the Captain said, "Pull" or "Pull with me" four times.

Although the FDR and CVR stopped recording at approximately 0150:35.98, radar analysis of a primary target consistent with Flight 990 showed the airplane ascending to approximately 24,000 feet where it entered a final dive toward the ocean.

From the time that the autopilot was disengaged at 0149:45 to the end of the FDR and CVR recordings there were no radio transmissions either to or from the accident.

Upon departure from JFK, Flight 990 was assigned transponder code 1712 and was in radar contact with New York ARTCC Atlantic Sector at the time of the accident. At 0154:00, the controller radioed Flight 990 stating, "EgyptAir nine ninety radar contact lost recycles [sic] transponder squawk one seven one two." There was no response from Flight 990, and the controller began contacting other and communications providers in an effort to locate Flight 990. Between 0156:40 and 0207:44, the controller called ARINC and enroute from Lufthansa and Air France, requesting their assistance in contacting Flight 990. The controller also contacted the 24th Air Defense Squadron for assistance. None of these other agencies or were able to contact or locate Flight 990.

The wreckage of EgyptAir Flight 990 was found in two debris fields about 1200 feet apart. The main debris field, centered at 40º 20' 51" N, 69º 45' 24" W, contained the bulk of the airplane fuselage, wings, empennage, right engine, and flight recorders. A smaller debris field, slightly northwest of the main area, consisted mainly of parts associated with the left engine, portions of two wing panels, fuselage skin, horizontal stabilizer skin and the majority of the nose landing gear assembly. The parts, which were recovered in two recovery efforts, were generally small and fragmented. No substantial intact pieces of the fuselage or the flight control surfaces were recovered.

Although there were no specific maintenance issues related to Flight 990 set out in the airplane's maintenance records, the outbound Flight 989 segment from Newark to Los Angeles on October 30, 1999 had an event, which may have affected Flight 990. The Captain of Flight 989 observed some unusual behavior of the autopilot. Captain Gamal Arram reported that the flight to Los Angeles was uneventful until approximately 20-30 minutes prior to landing. At that time, with the autopilot engaged and the airplane descending through 10,000 feet, Captain Arram noticed an unusual movement of the control column in both forward and aft directions. To him, it appeared that the autopilot was "hunting" for the correct column position, and he felt a series of "chops," similar to light turbulence, when this occurred. Because of the unusual behavior of the autopilot, Captain Arram disconnected the autopilot and flew the airplane by hand. He continued to hand fly the all the way to landing because the autopilot would not re-engage. Once on the ground, Captain Arram again tried to re-engage the autopilot, and this time, it successfully engaged.

After arriving at the gate, Captain Arram discussed the autopilot problem with the contractor maintenance engineer responsible for EgyptAir at Los Angeles. Because the condition was intermittent and because the autopilot was checked out on the ground, the event did not raise a safety of flight issue in Captain Arram's mind. Consequently, Captain Arram did not note this event in the technical log.

1.2 Injuries to Persons

INJURIES	CREW	PASSENGERS	OTHERS
Fatal	14	203	0
Serious	0	0	0
Minor/None	0	0	0

Flight 990 carried 203 passengers, 10 flight attendants, and 4 flight crewmembers. There were no survivors. Victim identification was made on the basis of DNA and other forensic analysis conducted by the Medical Examiner for the State of Rhode Island.

1.3 Damage to

The was destroyed in the accident, with the wreckage falling into two debris fields, located approximately 1200 feet apart, about 60 miles southeast of Nantucket Island. The wreckage was in small, fragmented pieces. Although the size of the recovered airplane wreckage was consistent with pervasive impact damage, there was no evidence to show that all observed damage was caused by impact with the water. The largest pieces of wreckage recovered were the left engine and most of the nose landing gear assembly, which was found in northwest of the main debris field.

1.4 Other Damage

There was no property damage except to the accident airplane.

1.5 Personnel Information

1.5.1 The Command Crew

The Captain of the command crew was Captain Ahmed El Habashy, age 57. Captain Habashy received his Egyptian Airline Transport Pilot license in 1970, held type ratings in the B-707, B-737, and B-767 (200 and 300 series), and had been employed by EgyptAir since 1963. He had accumulated about 14,300 total flight hours. His most recent medical examination was on October 21, 1999 when he was found to fit to fly with glasses.

The command captain passed his first full medical examination and psychiatric assessment on October 23, 1960. He passed his medical examination with psychiatric evaluation for his Commercial Pilot license on December 5, 1963, and passed his medical examination with psychiatric evaluation for his Airline Transportation Pilot license on February 12, 1970. There was no reported history of psychiatric consultation nor any reports regarding his behavior, either professionally or in groups, throughout his career as a pilot.

Captain Habashy arrived in New York during the afternoon of October 28, 1999, after serving as a command crewmember about EgyptAir flight 989 from Cairo to New York. He remained in New York until departing on October 31, 1999 as the Captain of the command crew of Flight 990.

The First Officer of the command crew was Adel Anwar, age 37. First Officer Anwar received his Commercial Pilot license in 1990, held type ratings in the B-737 and B-767 (200 and 300 series), and had been employed by EgyptAir since 1992. He had accumulated about 3,360 total flight hours. His most recent medical examination was on October 6, 1999 when he was found fit to fly.

The command first officer passed his first full medical examination and psychiatric assessment to be student pilot on March 4, 1982. He passed his medical examination with psychiatric assessment for his Commercial Pilot license on December 7, 1989 and passed a full medical examination and psychiatric assessment to be an EgyptAir pilot on July 30, 1992. There was no reported history of psychiatric consultation nor any reports regarding his behavior, either professionally or in groups, throughout his career as a pilot.

First Officer Anwar arrived in New York during the afternoon of October 28, 1999, after serving as an active crewmember aboard EgyptAir Flight 989from Cairo to New York. He remained in New York until departing on October 31, 1999 as the First Officer on the relief crew.

1.5.2 Relief Crew

The Captain of the relief crew was Captain El Sayed Nour El Din, age 52, Captain Nour El Din received his Egyptian Airline Transport Pilot license in 1979, held type ratings in the Airbus A300-600R, the B-737-500, the Airbus A300-B4, and the B-767, and had been employed by EgyptAir since 1981. He had accumulated about 12,200 total flight hours. His most recent medical examination was on June 6, 1999 when he was found fit to fly with glasses.

Captain Nour El Din passed his medical examination with psychiatric evaluation for his Commercial Pilot license on May 10, 1979 and passed his medical examination with psychiatric evaluation for his Airline Transportation Pilot license on November 8, 1979. He also passed the full medical examination to be an EgyptAir pilot on May 26, 1980. There was no reported history of psychiatric consultation nor any reports regarding his behavior, either professionally or in groups, throughout his career as a pilot.

Captain Nour El Din arrived in New York during the evening of October 28, 1999, after serving as a command crewmember aboard EgyptAir Flight 990 from Los Angeles to New York. Previously, Captain Nour El Din had operated EgyptAir Flight 989 as the command captain from Cairo to New York on October 21, 1999, and then on EgyptAir Flight 989 from New York to Los Angeles on October 23, 1999. Captain Nour El Din remained in New York until departing on October 31, 1999 as Captain of the relief crew.

The First Officer of the relief crew was First Officer Gamil El Batouty, age 59. First Officer El Batouty received his Commercial Pilot license in 1965, held type ratings in the B-737 and B-767 (200 and 300 series), and had been employed by EgyptAir since 1987. He had accumulated about 12,500 total flight hours. His most recent medical examination was on July 28, 1999 when he was found fit to fly with glasses.

First Officer El Batouty passed his full medical examination and psychiatric assessment, which was performed by the Egyptian Air Force Medical Council as part of his full medical examination for fitness to be a pilot in the Egyptian Air Force, on December 11, 1958. He passed his medical examination for his Commercial Pilot license on July 27, 1961. A psychiatric assessment was not conducted as part of the medical examination for the relief first officer's medical review for his Commercial Pilot license. During his military and civilian flying career there was no reported history of psychiatric consultation nor any reports regarding his behavior, either professionally or in groups.

Prior to his employment at EgyptAir, First Officer El Batouty was employed as a flight instructor for the Egyptian military and later for a civilian flight training institute in Egypt.

First Officer El Batouty arrived in New York during the evening of October 28, 1999 after serving as a command crewmember aboard EgyptAir Flight 990 from Los Angels to New York. Previously, he had been the First Officer on the command crew aboard EgyptAir Flight 989 from Cairo to New York on October 21, 1999 and EgyptAir Flight 989 from New York to Los Angeles on October 23, 1999. First Officer El Batouty remained in New York until departing on October 31, 1999 as the First Officer of the relief crew.

1.5.3 Other Pilots As Passengers

In addition to the command and relief crewmembers, Flight 990 carried additional EgyptAir flight crew personnel as passengers. The CVR transcript shows that their presence was not anticipated by Captain Habashy and that it was a source of discussion in the cockpit. Among the additional EgyptAir was Captain Hatem Roshdy, the B-767 chief pilot. Capt. Hatem had been employed by EgyptAir since 1968 and had previously served as a pilot in the Egyptian military. He received his Egyptian Airline Transport license in 1986. His most recent medical examination was on May 23, 1999 when he was found to be medically fit to fly with glasses. Captain Hatem was viewed as a highly respected and accomplished chief pilot. In addition to Captain Hatem, First Officers Hisham Farouk and Raafat Aiad were also on board Flight 990.

1.6 Information

EgyptAir and ECAA records show that SU-GAP was a Boeing 767-366 Extended Range (ER), serial number 24542, and line number 282. SU-GAP was delivered to EgyptAir new on September 26, 1989. SU-GAP was granted an export Certificate Airworthiness number E248722 by the FAA on September 26, 1989, and Certificate of Airworthiness number 721 by the Arab Republic of Egypt, Ministry of Civil Aviation on September 26, 1989. This certificate was renewed on September 26, 1998 and valid until September 25, 2000. The Ministry of Civil Aviation also issued SU-GAP a certificate of registration number 857. At the time of the accident, the had 33,354 total hours and 7,594 total cycles. It was configured for 217 passengers as follows: 10 first class, 22 business class, and 185 coach.

The was equipped with two Pratt & Whitney PW 4060 turbo fan engines with a 60,000 pound thrust rating. The left and right engines were removed in February 1997 and March 1997, respectively, for upgrade and complete refurbishment. They were disassembled as necessary, refurbished, modified, inspected, reassembled, and tested in accordance with Pratt & Whitney engine manual procedures. The engines were test run and were released for a return to service in November 1997 and February 1998.

The airplane, SU-GAP, departed Cairo on October 30, 1999, as EgyptAir 989 on a regularly scheduled flight from Cairo to Los Angeles with an intermediate stop at JFK. EgyptAir 989 was dispatched with the left thrust reverser out of service, because of a thrust reverser actuator leak that had been entered in the Technical Logbook on October 27, 1999, in Cairo.

On October 30, 1999, EgyptAir 989 was scheduled to land at JFK but diverted to Newark International Airport (EWR) because of weather. After a crew change, EgyptAir 989 departed EWR for LAX.

The airplane turned to EgyptAir 990 on October 30, 1999 and was scheduled to operate from LAX to Cairo with a stop at JFK. During the pre-flight inspection at LAX, it was discovered that the number seven tire on the main landing gear was flat. Both the number seven and eight tires were replaced, and EgyptAir 990 departed LAX for JFK. EgyptAir 990 landed at JFK at 2348 EDT, and arrived at the gate at 0010 EDT on October 31, 1999.

1.6.1 Accident Maintenance Records

1.6.1.1 Inspection History

Scheduled maintenance checks are approved by the ECAA (MSR Operations Specifications D88), and are in accordance with the Boeing 767 Maintenance Planning Data (MPD) document.

<u>Transit Check:</u>	Before each flight.
<u>After Landing Check (ALC):</u>	After each arrival to base.
<u>Daily Check:</u>	Every 48 hours that the airplane is in service.
<u>Ramp Check:</u>	Every 8 day (calendar).
<u>Check “A” Systems and Multiples:</u>	Every 500 flying hours and multiples.
<u>Check “A” Structure and Multiples:</u>	Each 300 cycles, with the nearest “A” system check.
<u>Check “C” Systems and Multiples:</u>	Every 6000 flying hours or 18 months, whichever comes first
<u>Check “C” Structure and Multiples:</u>	Every 3000 cycles or 18 months, whichever comes first.

The EgyptAir records reflected the following with regard to SU-GAP:

(a) The last “Transit Check” was completed on October 30, 1999, at JFK. No discrepancies were noted. Included in the check was the inspection of engines for damage, latch security, and fluid leakage.

(b) The last “A Check” was completed on October 4, 1999, at CAI, with total hours 33,140 and total cycles 7,533. Minor discrepancies included:

    (1) Total cycles were not noted on the Maintenance Check Certification Cards, even though a space was provided. However, cycle data is computerized and was available.

    (2) An open item (nonroutine card number 007811) noted a 1- by 1-inch section of skin damage on the number two engine-pylon that received temporary repair.

    (3) On the post check inspection, high-speed tape was used to cover a number two engine pylon-access latch. A replacement latch (part number 9284-4) was not available, and the temporary action resulted in an open item.

(c) The last “C Check” was completed on May 2, 1998, at CAI, with total hours 28,587 and total cycles 6,313. The check included the following events: flight data recorder was sent to the avionics shop for repair, the three landing gears were removed and sent to a repair facility for overhaul, the lower thrust reverser (TR) actuator on the number two engine was replaced because of a hydraulic leak, and a worn left side lower blocker-door hinge on the number two engine TR was replaced. Minor discrepancies included:

    (1) On the post check inspection, the positive pressure-relief valve test (maintenance task card 21-010-01) was not accomplished because tester and spares were not available. The check was not accomplished until September 1998.

In addition, the Airframe Airworthiness Directive (AD) report, issued by MSR’s technical division for SU-GAP, was reviewed. The document denotes the subject matter of the AD, methods of compliance, status, and times and dates of repeating intervals. The following selected AD’s were reviewed in detail: AD 86-22-11R0, AD 90-01-09R0, AD 93-05-13CR0, AD 93-13-01R0, AD 94-12-10R0, AD 94-12-10R0/SB 767-78A0046/SB 767-78-0051/SB 767-78-0062R2, AD 96-1910R0, AD 97-19-15R0, AD 98-07-26R0, and AD 98-13-12R0: No discrepancies were noted.

Also data from EgyptAir's System Reliability Report were reviewed. No unacceptable maintenance trends or discrepancies were noted.

1.6.1.2 Events on Earlier Flights

Prior to the departure of Flight 990 from JFK on October 31, 1999 three technical reports were recorded. They are as follows:

a. The number one engine thrust reverser was deactivated by EgyptAir on October 28, 1999 due to a lower right hydraulic actuator leak.

b. On October 29, 1999 an entry was made in the defect log (no. 004962) because the tail skid drag shoe paint was scratched, indicating the possibility of a tail strike. Examination of the tail skid revealed that it was serviceable and did not adversely affect the safe operation of the airplane.

c. Flight crewmembers had reported that an alert indication for the left air-conditioning pack temperature (L PACK TEMP) had appeared during prior flights on airplane SU-GAP. The alert indicated that the automatic function of the pack control system had malfunctioned, or there was an overheat condition in the pack outflow

According to the respective flight crews, the L PACK TEMP alert occurred on EgyptAir Flight 989, which was the Cairo to EWR leg on October 30, 1999 and also on EgyptAir Flight 990, the LAX to JFK leg of on October 30, 1999. The crewmembers of those flight legs reported that when the Quick Reference Handbook (QRH) procedures were followed, the advisory light extinguished, and the system operated normally.

Review of the 's Technical Logbook did not indicate that this item had been entered for EgyptAir Flight 989 (CAI-LAX) or EgyptAir Flight 990 (LAX-JFK).

In addition to these defects, the command crew Captain on October 30, 1999 Flight 989 from Newark to Los Angeles observed some unusual behavior of the autopilot during the approach into Los Angeles. The details of this event are included in Section 1.6.4.

1.6.2 Boeing 767-300 Elevator System

1.6.2.1 Description

The purpose of the elevator control system is to control the pitch attitude around its lateral axis. The elevators create pitching moments to change pitch attitude or maintain a temporary or short period change in pitch attitude. Pitching moments are created by deflection of the elevator surfaces into the airstream. Elevator control affects altitude control, takeoff, climb, level cruise, descent and landing flare. The elevator is used to control pitch for short term periods only. Long term changes in pitching moments are accomplished by horizontal stabilizer trim changes. The elevators can be controlled either manually or through the autopilot system.

Manual elevator control is achieved by movement of the captain's or first officer's control column. Movement of the column causes cables to move through two separate cable runs that rotates the aft quadrant/torque tube assemblies to provide control input to three power control actuators (PCA), which hydraulically drives the elevator. All three hydraulic systems power actuators on both left and right elevators. Each PCA is power from one individual hydraulic system.[5]

A feel and centering unit provides an artificial feel force and neutral position for elevator and control column movement. The feel computer supplies a variable hydraulic pressure to the feel actuator based on changes in air speed and stabilizer position to provide a psychomoter feedback for the pilots.

The elevator control system consists of two equal systems in parallel. The captain's control column is hard connected to the PCA input levers on the left outboard elevator and the first officer's control column is hard connected to the PCA input lever on

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[5] For autopilot control, please refer to Section 1.6.3 regarding the autopilot system.

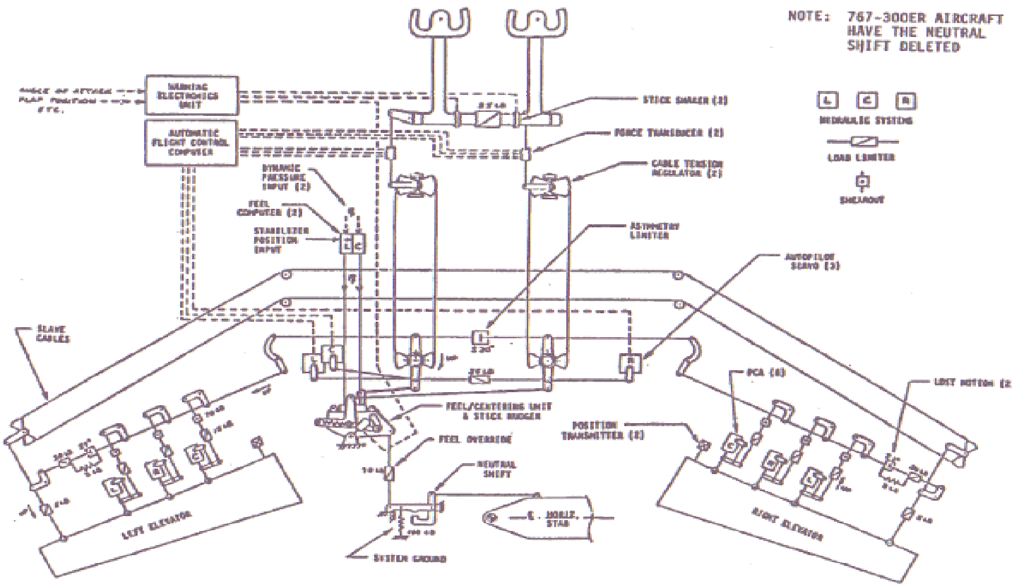
the right outboard elevator. The left and right elevator control systems are interconnected through two override mechanisms, one at the control columns and the second at the elevator aft quadrants. The captain's and first officer's elevator control systems have equal authority with the two systems normally acting together as one system because of interconnection through the override mechanisms. One system is sufficient to control the airplane and each control is independent of the other if one system is immobilized; that is, the captain flies the left elevator and the first officer flies the right elevator if one system jams.

The slave interconnect cable system connects the left and right elevators and provides an alternate means of controlling both elevators in the event that linkage is broken between the aft quadrant and the PCA input. Under normal operation, lost motion compensators prevent the slave cable from interfering with PCA operation.

Input pogos are used to connect each PCA input summing lever to the input bellcrank. In case of a PCA control valve jam, the input pogo would break out after a column force of 15 pounds over the normal feel forces has been applied and allow the other two PCA's to continue positioning the elevator surface.

Shear rivets are also provided between the levers of each input bellcrank. In case of jamming at the input pogo linkage, the pilot could apply a column force of 52 pounds over the normal feel force to shear the rivets, and allow the other two PCA's to continue positioning the elevator surface.

. Based on the airplane angle of attack compared with the shape of the wing as determined by flap and slat positions, stall warning modules signal the column stick shakers and stick nudger to warn of a stall situation.



NOTE: 767-300ER AIRCRAFT HAVE THE NEUTRAL SHIFT DELETED

Figure 3.1-3. Elevator Control Schematic

Figure 2 Boeing 767-300 Elevator Control Systems

1.6.2.2 Possible Failures Modes

The following failure scenarios relating to the elevator system were considered as possible causes for the EgyptAir 990 accident:

1. Single elevator body cable failure
   a. Broken cable
   b. Jammed cable
2. Erroneous stick-nudger activation with and without stiff spring
3. Failed slave cable (jammed cable)
4. Jamming of elevator input control at one side (input section from elevator control column to the PCA's)
5. Single linkage disconnect downstream of feel unit
6. Failed component falling on elevator cables
7. Failure of feel unit ground path
8. Cable tension regulator failure

9. Hydraulic system failure to one surface
10. Aft pressure bulkhead failure
11. Elevator position transducer disconnect
12. Autopilot single channel hardover
13. Centering mechanism failure
14. Single PCA valve disconnect on the right elevator surface
15. Single PCA valve jam on the right elevator surface
16. Dual PCA valve disconnect on the right elevator surface
17. Single PCA valve disconnect followed by single PCA valve jam on the right elevator surface.
18. Dual PCA valve jam on the right elevator surface.

1.6.3 Boeing 767-300 Autopilot System

1.6.3.1 Description

The autopilot (A/P) provides automatic control of the primary flight control systems for the roll, pitch, and yaw axes through all phases of flight except takeoff (T/O). The autopilot system through the autoflight[6] system, provides display data to the Electronic Horizontal Situation Indicators (EHSI) and Electronic Attitude Director Indicators (EADI) of the Electronic Flight Instrument System. Autopilot systems drive hydraulically powered servo actuators which, in turn, drive hydraulic Power Control Actuators (PCA's) connected to the ailerons, elevators, and rudder. The PCA's are controlled either manually or from autopilot system servos.

All primary flight control surfaces are controlled by PCA's. Mechanical and hydraulic devices are used to provide normal control system feel. The PCA's are controlled through a mechanical linkage. The mechanical linkage is moved by:

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[6] Autoflight system includes autopilot, flight director, yaw damper and Mach trim

- Conventional manual flight controls consisting of control columns, cables, quadrants, etc.
- Actuators respond to either manual or autopilot input signals. Servos respond to autopilot command signals.

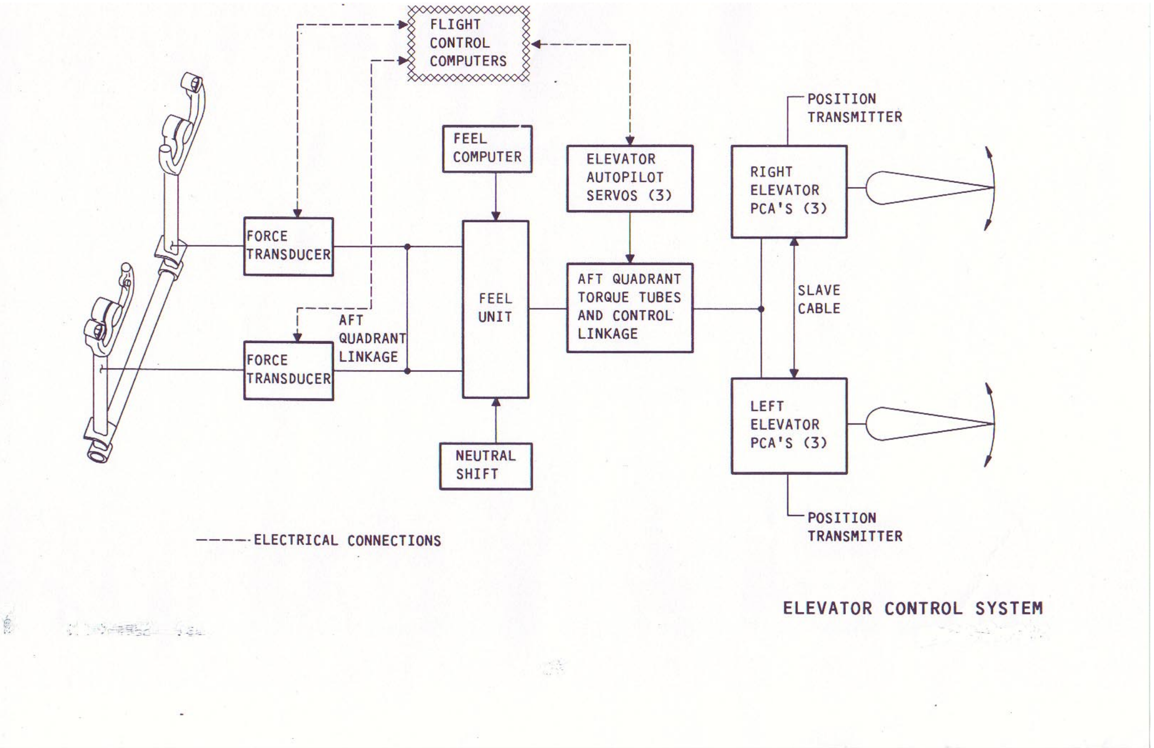
Two or more actuators drive each primary flight control surface. Each PCA is powered by only one hydraulic system. The actuators' and servos' electrical feedback (position) neutralizes the control input (command) from the system computer when the new position is reached. For the aileron and elevator systems, the action of the summing linkage maintains the PCA control lever in the neutral position. The linkage sums the motion of the control input and the output piston, which move in opposite directions. The resultant establishes the position of the control lever.

The PCA's continue to move in the commanded direction as long as the control lever is displaced from neutral. Three Elevator Autopilot System (EAS) servos drive the elevator PCA's. The EAS servos are aft of the horizontal stabilizer.

Control inputs are conditioned to provide a sense of feel and centering. Feel is introduced by a feel actuator and feel unit. The feel computer uses dynamic pressure "computed airspeed (CAS)" and stabilizer position to vary the feel. The feel unit includes the centering device.

Autopilot input is controlled by three Flight Control Computers (FCC's) linked to three independent pitch autopilot servos. Each servo independently drives the aft quadrant torque tubes. The servos contain linear variable differential transducers (LVDT's) which provide servo and surface position feedback to the FCC's. A force transducer on each control provides inputs to each FCC. This allows manual control when the autopilot is engaged in the control wheel steering (CWS) configuration. Elevator control movements are finally routed to both left and right power control actuators by mechanical linkage. Position transmitters are located at each elevator to provide control surface position.

If the autopilot is engaged, the autopilot servo then drives the linkage to the PCA's and backdrives the control cables to move the control columns. A diagram of this system is reproduced below in Figure 3.



Figures 3 Autopilot Block Diagram

The Disengage Bar, which is located on the glare shield, disengages all three autopilots when the bar is down. When the bar is up, the servos may be engaged; when down, 28 Volt dc is removed from the servos, preventing engagement. When the bar is down, a day glow orange strip is visible, annunciating the disengaged position of the switch. In addition to the Disengage Bar, there is an A/P disengage switch on the control wheel which must be pressed and released a second time to reset the warning.

With the autopilot engaged, solenoid valves SV1 and SV2 are open, the detent pistons are pressurized and the internal crank is clamped on the center of the actuator piston. When the electro-hydraulic servo valve (EHSV) receives a command from the FCC, hydraulic pressure is ported to one end of the actuator piston. The detent pistons carry the internal crank with the actuator piston to its commanded position. The output crank moves the linkage to the elevator power control actuators while the output position through the LVDT sends position information back to the FCC to null the command signal and stop the elevator.

The FCC transitions from Command (CMD) to OFF if:

1. FCC memory fails or self-test monitors are not verified.
2. Rudder solenoid is energized.
3. Aileron or elevator servo or servo loop fails.
4. Any two identical inner loop sensors fail.
5. FCC electrical power monitor detects a failure.
6. Aileron exceedance detector monitor detects a failure.
7. ALT HLD or override function cannot be performed.
8. Autopilot Disengage switch is pressed.
9. Air data computer stability signals invalid for seven seconds.

1.6.3.2 Mach Trim System

The Mach Trim System commands the stabilizer towards airplane nose up direction at high speed to compensate for the airplane's inherent nose down tendency at such high speeds. The system operation is summarized below.

- Mach trim system is controlled by two SAM's (Stabilizer/Aileron Modules).
- Mach trim engages 20 seconds after airborne and flap full retraction.
- One SAM controls the Mach trim system at half the normal stabilizer operating speed.
- SAM controls the stabilizer according to following schedule:

Computed Mach	**Stabilizer**
0.33	0
0.78	-0.48
0.88	-0.82

with linear variation

The computed Mach signal is received at the SAM from the ADC. The stabilizer is trimmed per the above schedule about the "synched" Mach and the stabilizer setting. The "synched" values are set following a pilot control wheel trim command or following disengagement of the autopilot. Total Mach trim authority above a given "synched" point is 0.82 °. Mach Trim system should move the stabilizer with increasing Mach number unless any of the following conditions exists:

- Autopilot system is engaged.
- Manual electric trim is being used.
- Both elevators control columns are forward more than 2.2 - 2.7 degrees.

1.6.3.3 Behavior of EgyptAir 990 Upon Autopilot Disconnect

Based on Captain Gamal Arram's report of the erratic autopilot behavior on October 30, 1999, during the EWR-LAX segment of Flight 989, the Flight Data Recorder Track No. 5 (NY / LA) was reviewed. The FDR showed that the flight crew disengaged the autopilot four times as follows:

1. At altitude 10368 ft (FDR Subframe 5502), the autopilot was disengaged[7] for no obvious reason. The right elevator dropped from 0.88 to 0.53°, and when the autopilot was re-engaged, the right elevator returned to 0.8°.
2. At altitude 8896ft (FDR Subframe 5574), the autopilot was disengaged for no obvious reason.
3. At altitude 8672 ft (FDR Subframe 5582), the autopilot was disengaged for no obvious reason. The right elevator dropped from 0.70 to 0.53°, and when the autopilot was re-engaged, the right elevator returned to 0.7°.
4. At altitude 7552 ft (FDR Subframe 5628), the autopilot was disengaged for no obvious reason and remained disengaged to the end of the flight. The right

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[7] In all four cases, the FDR showed that autopilot was disengaged while the localizer mode was engaged and glide slope mode did not capture.

elevator dropped from 0.70° to 0.53°. (Refer to the docket Exhibit #10C attachment for full details)

The Captain of Flight 989 reported that he had disengaged the autopilot in the four cases in response to a sudden movement of the control column (control column displacement parameter is not recorded in FDR). Figure 4 below shows the elevator behavior just after autopilot disengagement in three cases.

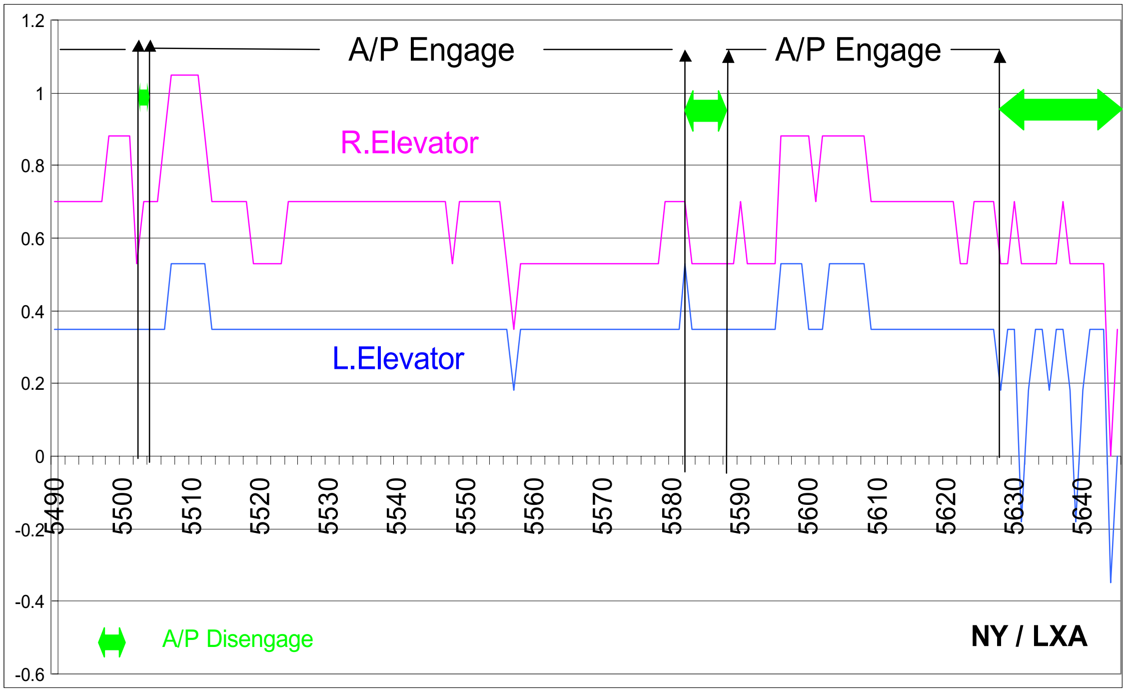

Figure 4 Elevator movements with autopilot disengagements, Flight NY/LAX

This elevator movement was compared with elevator motion following the autopilot disconnect during a flight from Rome to Cairo on the sister B-767. SU-GAO. The FDR was analyzed after the flight for elevator behavior and all other flight controls. Elevator movement was different (see figure 5) on the test flight in comparison with the accident.

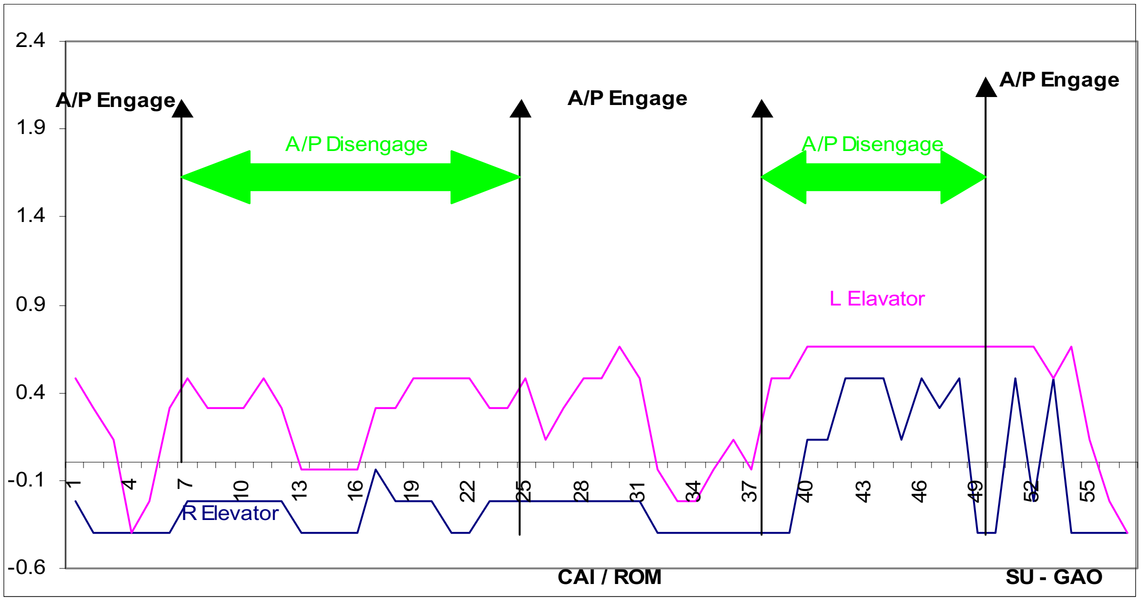

Figure 5 Elevator movements with autopilot disengagements, Flight CAI/ROM

1.6.4 Other Related Systems

1.6.4.1 Hydraulic Motor Generator System

The hydraulic motor generator is a standby electric power source used in emergency situations. The hydraulic motor generator is activated automatically when power loss occurs at both main AC Buses during flight. The hydraulic motor generator provides power to:

1. L & R transfer AC Buses.
2. Captain 115 AC voltage flight instrument Bus.
3. Hot Battery Bus.

The hydraulic motor generator uses the center hydraulic system pressure, which is pressurized by two electric and one air driven pumps. If both engines are shut down, the center hydraulic system will not be activated either from the two center system electrical pumps or from the air driven pump.

1.6.4.2 Ram Air Turbine (RAT) System

The RAT provides reserve hydraulic power to the center hydraulic system for operation of the primary flight controls. The RAT is a ram air turbine that drives a hydraulic pump and is stowed inside the aft right wing –to-body fairing when not in use. The RAT could be deployed either manually, using a control switch in the cockpit, or automatically if both engines' high rotor rpm drop below 50 % with indicated airspeed higher than 80 knots during flight. The RAT hydraulic pump supplies 11.39 gallons/minute at 2140 psi. The Operation Manual does not include any speed limitation for RAT deployment.

1.6.4.3 Horizontal Stabilizer control system:

The horizontal stabilizer is a movable airfoil which trims the airplane along its longitudinal axis. It is controlled by electrical inputs which are received by two stabilizer control modules (STCM). The STCM's are powered by the left and center hydraulic systems. The STCM's have three modes of control:

1. Autopilot control through flight control computers
2. Two manual electrical trim switch on the control wheels and alternate control switches
3. Mach trim mode

The control and priority of the stabilizer operation is done by two electronic modules "Stabilizer trim and Outboard Aileron lockout SAM". Only one SAM takes control at a time, with the other one in standby condition. The trim rate changes according to airspeed between 0.2 to 0.5 degree/ second when two (STCM) are active or 0.1 to 0.25 degree/ second when only one STCM is active.

1.7 Meteorological Information

The closest upper air surrounding to the accident site was from Chatham, Massachusetts located approximately 83 miles north of the accident site. The 0000Z sounding on October 31, 1999 provided data for 34,000 feet (the closest reporting altitude to Flight 990's cruising altitude of 33,000 feet) showing an air temperature of –51.7ºC, dew point –65.7ºC, and wind from 295º at 59 knots. There were no in-flight weather advisories issued by the NWS and no relevant weather reported by radar, satellite, or other pilots.

1.7.1 Surface Observations

The surrounding area was documented by meteorological aerodrome reports or METARs for conditions likely encountered. All cloud heights in this section are reported above ground level (AGL).

Nantucket Memorial Airport, Nantucket Island, Massachusetts (KACK)

Nantucket Memorial Airport is located approximately 55 miles northwest of the accident site, at an elevation of 48 feet. Nantucket reported the following weather conditions surrounding at the time of the accident:

> KACK weather at 0653Z, wind from 170 degrees at 9 knots, visibility 9 miles, sky clear below 12,000 feet, temperature 12.8 degrees Celsius (C), dew point temperature 11.7 degrees C, altimeter 30.39 inches of mercury (Hg). Remarks: Automated Surface Observation System (ASOS) observation, sea level pressure 1027.9 millibars (mb), thunderstorm sensor not operating.
>
> KACK weather at 0553Z, wind from 170 degrees at 7 knots, visibility 10 miles, sky clear below 12,000 feet, temperature 12.2 degrees C, dew point temperature 11.7 degrees C, altimeter 30.41 inches of Hg. Remarks: ASOS observation sea level pressure 1028.5 mb.

John F. Kennedy International Airport, Jamaica, New York (JFK)

The flight departed from John F. Kennedy International Airport which is located 183 miles west of the accident site. The weather reported at the time of the departure to the accident period was as follows:

> KJFK weather at 0651Z, wind from 250 degrees at 3 knots, tower visibility 1/2 miles in mist, temperature and dew point at 11.1 degrees C, altimeter 30.38 inches

of Hg. Remarks: ASOS observation, surface visibility 1 1/4 mile sea level pressure 1028.6 mb.

1.7.2 Winds at Altitude

The winds from the surface to very high altitudes were measured and recorded using balloons carrying radiosonde equipment. This data is archived by the National Oceanographic and Atmospheric Administration (NOAA). The crash occurred at approximately 0700 UTC on 31 October 1999. The following are the most relevant radiosonde reports:

Station	Location Relative to the Crash Site	Time of Reading (UTC)	Time Relative to the Crash Time
Brooklawn, NY	143 nm West	0000	7 hours before
Chatham, MA	80 nm North	0000	7 hours before
Brooklawn, NY	143 nm West	1200	5 hours after
Chatham, MA	80 nm North	1200	5 hours after

No report is clearly the most representative of the accident site and time. The following is an average of the four reports and was used in the flight path reconstruction and the trajectory analysis:

Altitude (Ft MSL)	Wind Speed (knots)	Wind Direction (Degrees)	Temperature (° C)
800	17	201	14.0
2951	21	229	12.2
5271	22	245	10.4
10489	22	264	2.0
19095	35	279	-15.7
24484	41	280	-27.4
31087	42	289	-42.1
35048	45	288	-51.8

1.8 Aids to Navigation

1.8.1 Fixed Facilities (VOR, ILS, NDB, etc)

There is no evidence that the aids to navigation were not functioning properly or that operation of such facilities is relevant to this accident.

1.8.2 Air Traffic Control

1.8.2.1 ATC Environment

Around 0030, New York ARTCC (ZNY) began operating in a backup mode called Direct Access Radar Channel (“DARC”) to allow for maintenance of the primary system or “host.” The DARC does not have the flight plan processing capability of the host, thus, controllers must transfer data, either verbally or through paper flight strips. Prior to transitioning to DARC, all stored flight plans, including the one for Flight 990, were flushed from the system and printed.

As a result of the use of the DARC, Flight 990’s flight plan was not entered into the tracking system at the time the flight departed JFK. Consequently, ZNY initially did not have the Flight 990 routing and was required to locate the information for Flight 990 and to enter it manually.

1.8.2.2 Extracts From ATC Voice Transcripts[8]

The following excerpts from the FAA transcript of ATC communications relating to EgyptAir 990 illustrates the ATC problems prior to the accident. After Flight 990 departed JFK and was cleared direct to the SHIPP intersection, the following exchange occurred between the New York TRACON (N90) and the New York Center (ZNY). All times is UTC as shown on the transcript.

0624:46	N90	(unintelligible) Kennedy manual handoff EgyptAir nine ninety
0624:58	ZNY	doesn’t anybody know over at the tower that they gotta put these flights plans back in
0625:01	N90	its just disgusting
0625:03	ZNY	uh let me see if they put anything in I maybe just didn’t get the paper hang on I see him coming keep him coming

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[8] Refer to ATC Full voice transcripts on the docket exhibit 3 – Attachment A

0635:52	EgyptAir 990 passed the airspace boundary with Boston ARTCC approximately 90 miles southeast of JFK and was instructed to climb to FL 330 and to proceed direct to the DOVEY intersection.[9]

Shortly thereafter, two New York TRACON controllers discussed the lack of printed flight strips as follows:

632:10	KDR	wh it's the last ticket I've got on anybody
0632:13	R66	yeah cause nobody typed in the EgyptAir but they did type in lacasa
0632:15	KDR	yeah
0632:16	R66	ok I just wanted to make sure there wasn't anybody else so I didn't have to thro out the strips and then not find them
0632:18	KDR	well just because you don't have a ticket on anybody doesn't mean there's nobody else but that's all you know that's the best information I have got now
0632:23	R66	yeah if you don't have a ticket and its not in the machine I don't have a ticket either so we're both gonna be in the dark

The exact time that the Flight 990 flight plan was entered into the system cannot be determined. After the oceanic clearance was issued to Flight 990, the only other communication between the ZNY controller and the crew was a direction to change frequencies which was made and acknowledged at approximately 0147. The controller did not try to contact Flight 990 again until 0654 UTC when she radioed "EgyptAir nine ninety radar contact lost recycles [sic] transponder squawk one seven one two." There was no response to this communication or to any other attempts to contact Flight 990. EgyptAir 990 disappeared from the radar screen at time 0649:53 UTC, thus the controller did not monitor the flight for approximately 6 minutes.

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[9] This new route crossing warning areas W105 & W506, where the flight level 110 to 500 is permissible when release to FAA

1.8.2.3 Video Recording[10]

There is no video recording of ATC information, and the SATORI playback system does not reflect an accurate picture of the image on the controller's screen.

ICAO DOC – 9426 Air Traffic Planning Manual Part1 Planning Factors. Section 2 Chapter 8 – Requirements for communication

8.4.8 when using such recording in investigations, it should, however, be kept in mind that what has been said in 8.4.6 above with respect to the relative value of voice recordings applies even more so to radar recordings. Recordings based on data as provided by radar antenna may have little resemblance to what the controller concerned saw on her display at the time of the incident in question because the controller may have used the off – centering device or limited the range on her display to suit her particular needs. To be conclusive, it would be necessary to record the presentation on each display used for control purposes…

1.8.2.4 Section R86 Radar Controller

Section R86 radar controller indicated that the controller usually works only day shifts and rarely worked an evening or midnight shifts (has no experience with backup mode (DARC) as normally maintenance is carried out during night shifts) also she stated that:

- MSR 990 was the only   using the southerly oceanic track (North Atlantic Track Zulu) during her session.
- She went to strip printer (away from her display by approximately six feet) To sort strips for approximately 30 to 45 seconds while MSR 990 was approximately 15 minutes from DOVEY intersection.

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[10] Annex 11 state that if the recording required for accident or incident investigations, they are to be retained for longer periods until it is evident that they no longer required.

1.8.2.5 Related Reports

During the course of the investigation, the ECAA was informed of an incident involving Royal Jordan Flight 262 which left JFK approximately three hours before Flight 990. The report is as follows:

> Flight RJ262 NYC / AMS
>
> Date: 31st Oct. 1999
>
> Take off from JFK, SID was Happie 2-Yahoo Trans.Whale, Eanancs. After cruising at FL330 with Boston ATC, I was looking head down to the left on NAV.Chart 3,4 Canada to pick some en route airports, suddenly the F/O Shouted "Allah Akbar, Allah Akbar, la Ilaha Ella Allah" repeatedly, so I looked at him and asked him (Awad) what happened… he said "Captain I saw a Fire ball like a shooting star passing ahead at us very close from right to left going down…. I said, "how far do you think it was passing ahead of us?"… He said "Captain I could say around less than 50 M."…I noticed from the way he was talking and from his look that it was serious, so I said to him "(Awad) do not worry, we have so many good Airports en-route anything happens God's will we will manage". I really do not know what hold me not to report that to ATC, but after EgyptAir Flight 990 accident in that area which had the SID clearance as we had, I found myself obliged to submit this report to you as it is never too late in improving aviation safety."

1.8.3 Radar Data

During the course of the investigation, radar data in digital form was collected and provided to the ECAA on a CD-ROM for analysis. After reviewing the data, the ECAA determined that no verifiable conclusions could be reached concerning certain unidentified primary targets without additional data concerning the radar system and its operating characteristics. Beginning in January 2000, the ECAA requested this additional data from both the NTSB and from the U.S. State Department. Although the ECAA only sought information concerning EgyptAir 990, the U.S. government refused to provide the data, claiming that it was "classified." The ECAA offered to make whatever arrangements might be necessary to handle properly any classified materials, but this offer was refused.

Nevertheless, the following information was developed for the NTSB docket regarding the types of radars in use and the nature of the returns captured by them.

A. Radar types:

Two types of radar are used in order to provide position and track information:

1. Air Route Surveillance Radar (ARSR) track during cruise at high altitudes between airport terminal airspaces:

    - ARSR have a range up to 250 NM. ARSR antennas rotate at 5 to 6 RPM, resulting in radar return every 10 to 12 seconds. Typically, the coverage areas of ARSR antennas overlap so a particular block of airspace will be viewed by several ARSR antennas. The data from these antennas are fed to an FAA central computer where the returns are sorted and the data converted to latitude, longitude, and altitude information. The converted data are displayed to the FAA Air Route Traffic Control Center (ARTCC) controller and recorded electronically. ARTCC radar data are typically reported using the National Track Analysis Program (NTAP) in text format. The raw data generated by each ARSR are not recorded in the NTAP file; only the computed position information is recorded.

    - Along the East and West coasts of the United States, ARSR are used by the FAA to provide air traffic control services, but they are primarily used by the United States Air Force (USAF) for air sovereignty mission purposes. The USAF 84th Radar Evaluation Squadron (84RADES) monitors the returns from these ARSR antennas and records the raw data generated by each. Thus, where the FAA and USAF share ARSR sites, the raw data from each ARSR that is used to compute the position information recorded in the FAA NTAP file is available from the records kept by the 84RADES. For a given, the position information reported in the FAA NTAP file is reflected in the data recorded for one or more of the ARSR sites by the 84RADES.

    - The ARSR radar stations that tracked EgyptAir 990 flight are

        - North Truro, Massachusetts (NOR)
        - Riverhead, New York (RlV)
        - Gibbsboro, New Jersey (GIB)
        - Oceana, Virginia (OCA).

2. FAA Airport Surveillance Radars (ASRs):

- These radars are short range (60 NM) and are used to provide air traffic control services in terminal areas. The FAA records the data received by each site in Continuous Data Recording (CDR) text format. The FAA ASR-9 radar at Nantucket, Massachusetts (ACK) received and recorded returns from EgyptAir 990 during the time of the accident.

- No other ASR facilities besides Nantucket, Massachusetts (ACK) tracked EgyptAir 990.

B. Types of radar returns:

1. Primary Radar Returns

    - A radar antenna detects the position of an object by broadcasting an electronic signal that is reflected by the object and returned to the radar antenna. These reflected signals are called primary returns.

    - Knowing the speed of the radar signal and the time interval between when the signal was broadcast and when it was returned, the distance, or range, from the radar antenna to the reflecting object can be determined.

    - Knowing the direction the radar antenna was pointing when the signal was broadcast, the direction, or azimuth, from the radar antenna to the object can be determined.

    - Range and azimuth from the radar antenna to the object define the object's position.

    - In general, primary returns are not used to measure the altitude of sensed objects, though the ARSRs do have altitude estimation capability. The 84RADES records this estimated altitude.

    - Primary returns contain no information about the identity of the object that reflected.

2. Secondary returns:

    - To improve the consistency and reliability of radar returns, are equipped with transponders that sense the beacon interrogator signals broadcast from radar sites, and in turn broadcast a response signal.

    - Even if the radar site is unable to sense a weak reflected signal (primary return), it may sense the response signal broadcast by the transponder and be able to determine the position.

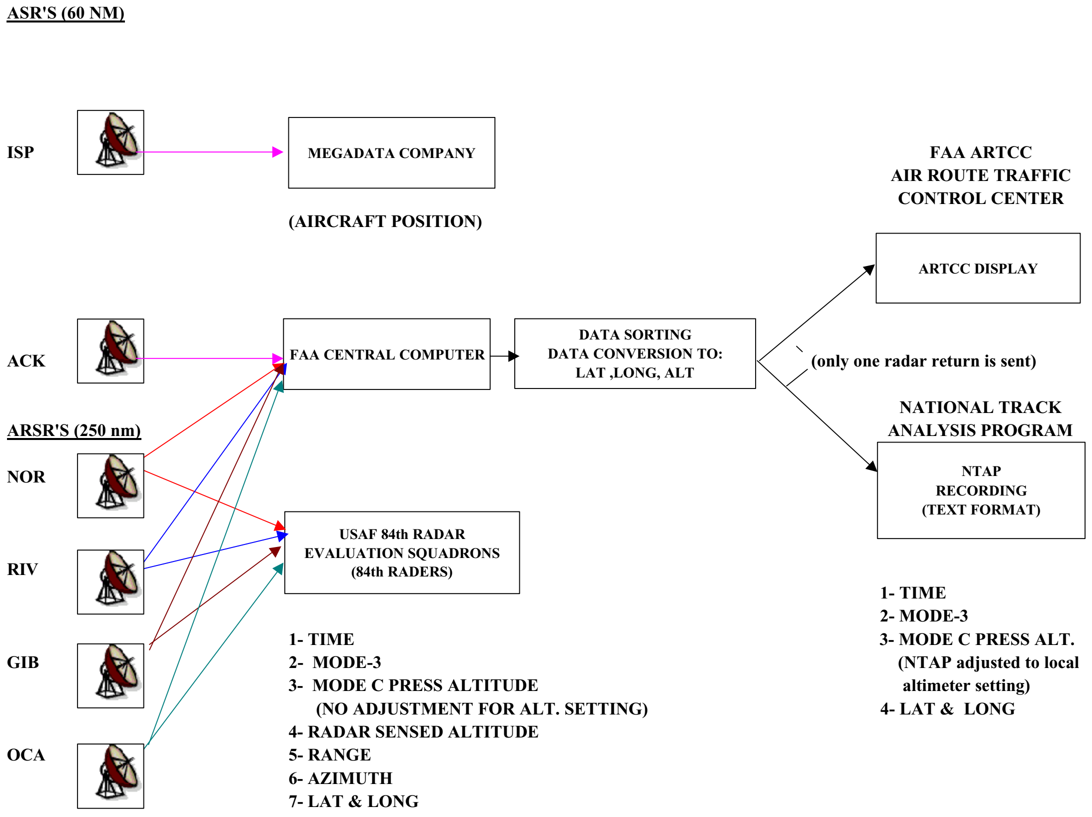
- The response signal can also contain additional information, such as the identifying Beacon Code for the flight and the pressure altitude which is called Mode C altitude.

- The Beacon Code identifier for EgyptAir 990 was 1712.

- Transponder signals received by the radar stations site are called secondary returns.

C. Radar data processing:

Refer to the radar data processing flow chart shown below in Figure 6



1- TIME
2- MODE-3
3- MODE C PRESS ALTITUDE
(NO ADJUSTMENT FOR ALT. SETTING)
4- RADAR SENSED ALTITUDE
5- RANGE
6- AZIMUTH
7- LAT & LONG

1- TIME
2- MODE-3
3- MODE C PRESS ALT.
(NTAP adjusted to local
altimeter setting)
4- LAT & LONG

ACK = Nantucket, Massachusetts
GIB = Gibbsboro, New Jersey
NOR = North Truro, Massachusetts
RIV = Riverhead, New York
OCA = Oceana, Virginia

Figure 6. Radar Processing Flow Chart

The radar charts showing EgyptAir 990's flight path are included below as Figures 7 and 8.

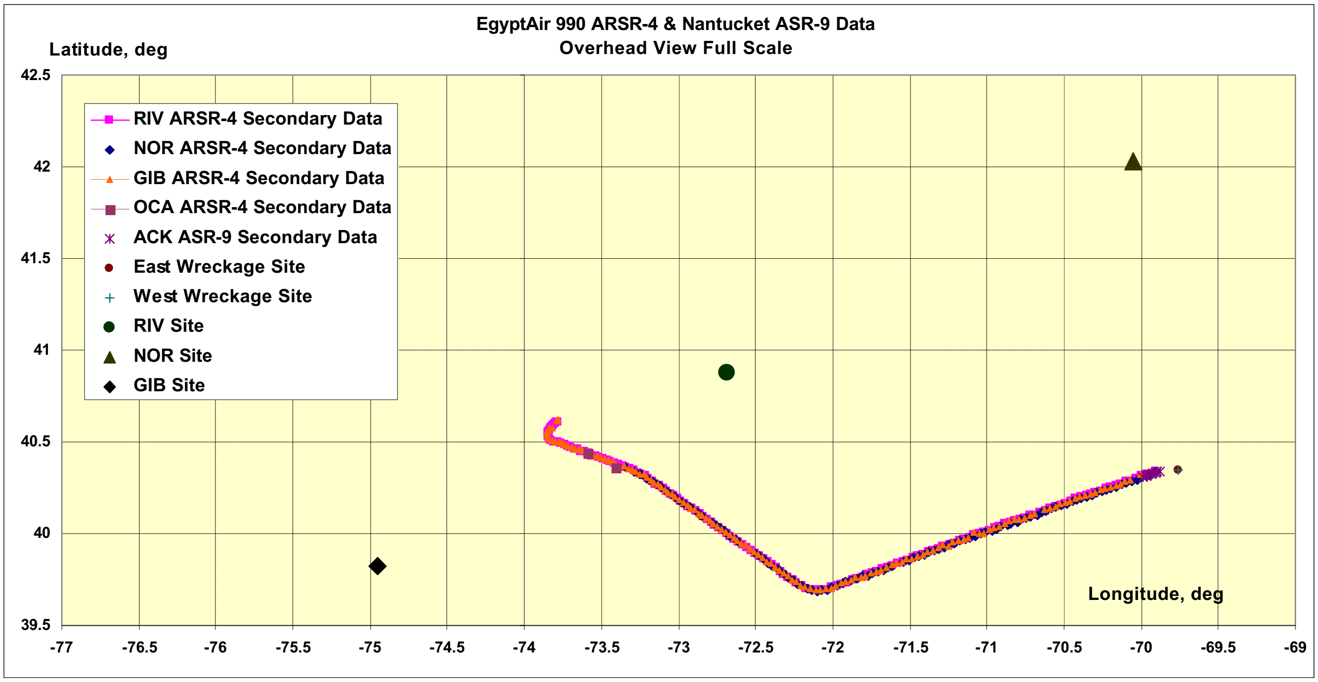


Figure 7 EgyptAir 990 Flight Path (longitude & latitude Full Scale)

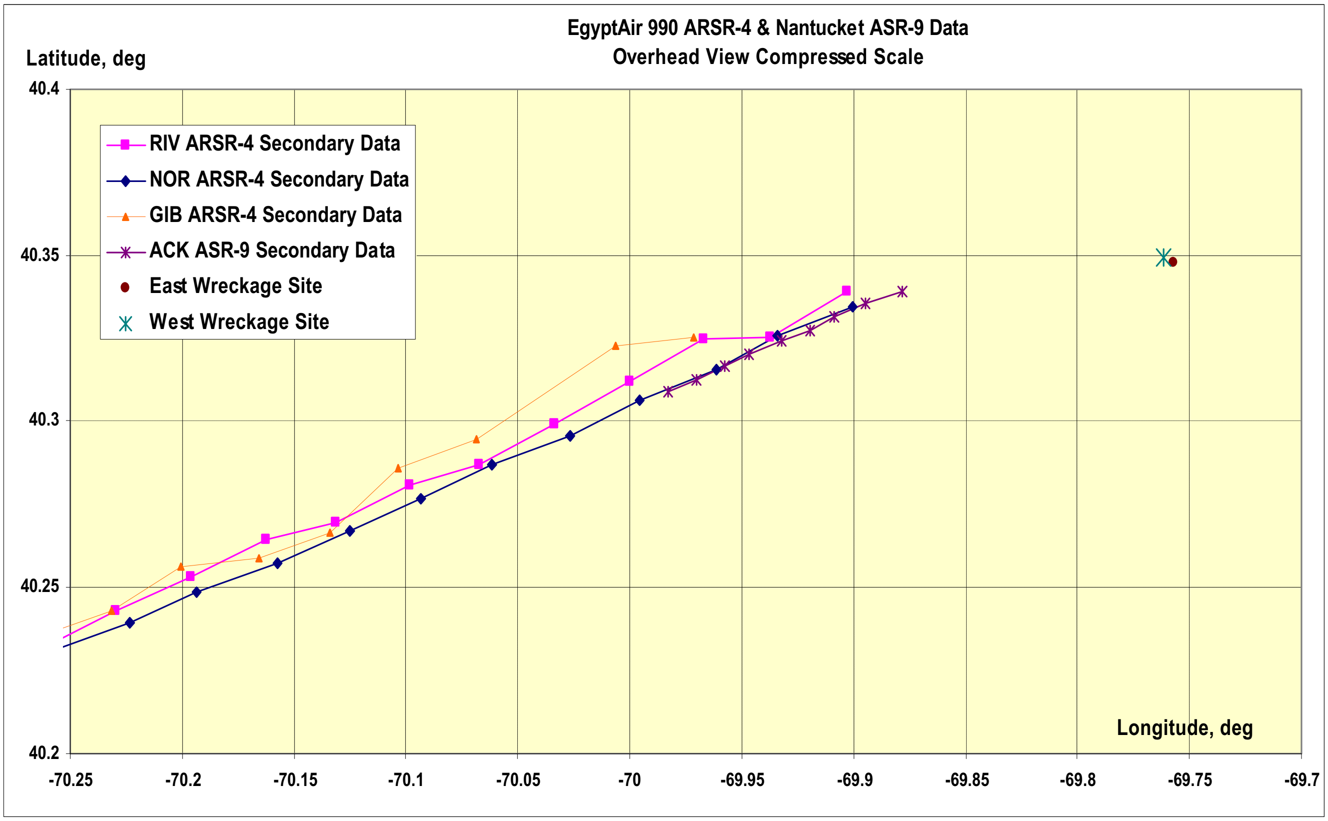


Figure 8 EgyptAir 990 Flight Path (longitude & latitude Compressed Scale)

1.9 Communications

All communications from the starting clearance to the oceanic clearance were clear and were recorded on the CVR.

After the oceanic clearance was issued for Flight 990, the only other communication between the ZNY controller and the crew was a direction to change frequency, which was made and acknowledged at approximately 0147. The controller did not try to contact Flight 990 again until 0154 when she radioed "EgyptAir nine ninety radar contact lost recycles [sic] transponder squawk one seven one two." There was no response to this communication or to any other attempts to contact Flight 990.

1.10 Aerodrome Information

EgyptAir 990 departed from John F. Kennedy International Airport for a scheduled passenger flight to Cairo, Egypt. No additional information is relevant to this investigation.

1.11 Flight Recorders

1.11.1 Cockpit Voice Recorder

Flight 990 was equipped with a Fairchild Model A-100 cockpit voice recorder (CVR), s/n 55155, which was recovered on November 14, 1999 by the U.S. Navy from the Atlantic Ocean 60 miles southeast of Nantucket Island. The exterior of the CVR showed evidence of significant structural damage. The front panel of the recorder, including the underwater locator beacon, was missing. The outer metal enclosure was heavily dented. However, the memory module and the tape were not damaged and contained four channels as follows:

First channel:	Contained audio information from the cockpit mounted area microphone with good audio quality.
Second Channel:	Contained audio information from the Captain audio selector panel. No much audio was recorded in this channel, as the Captain in command did not use his headset.

Third channel: Contained audio information obtained from the First Officer audio selector panel and contained good quality audio while the First Officer was wearing headset and "hot" boom microphone.[11]

Fourth channel: Contained audio information obtained from the jump seat/observer's audio panel. Not used in this flight.

Correlation of the CVR to Eastern Standard Time was established using times from the Nantucket Airport Surveillance Radar data, the 's digital flight data recorder (FDR), and the Air Traffic Control transcript developed by the FAA. The recording was examined on a computerized spectrum analyzer. This computer program allowed detailed analyses of both the analog waveform and frequency content as well as detailed timing information.

1.11.2 Flight Data Recorder

The accident airplane's flight data recorder (FDR), a Sunstrand Data Corporation Universal Flight Data Recorder, part number 980-4100-DXUS, serial number unknown, was recovered from the Atlantic Ocean by the U.S. Navy on November 9, 1999. A readout of the FDR was accomplished at the NTSB laboratory in Washington, DC. On April 18, 2000 a copy of the FDR tape was also provided to the ECAA. Readout of the FDR, (in EgyptAir's facilities in Cairo, Egypt) was accomplished using the laboratory's playback hardware, NAGRA tape recorder and interface connected to a Hewlett-Packard HP9000 minicomputer running TSB Canada-developed Replay And Presentation System (RAPS) software.

This review of the FDR data revealed the following:

a. An "Inner Marker" signal was recorded at 0150:17 and remained to the end of the recording.

b. A switch-over of the left engine's Electronic Engine Control (EEC) channel from channel "A" to channel "B" between 150:22 and 150:26. The EEC channel status is recorded on the FDR every 4 seconds.

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[11] According to the regulation, headset and "hot" boom microphone must be used up to 10,000 feet. Above this altitude, handset use is optional.

The raw-data, transcription file represented approximately 44 minutes of operation regarding the accident flight. The transcription file also included the landing at JFK immediately prior to the accident flight, as well as data following the transition to 25-hour-old data.

Correlation of FDR data to Radar Local Time:

The time of each subframe of accident flight FDR data was adjusted to local time (Eastern Standard Time). By correlation of Mode C radar data returns recorded by the Nantucket Airport Surveillance Radar (ASR-9), each second of FDR data was adjusted using the following equation:

Local Time = (FDR Elapsed Time) + 418.98 seconds. The adjusted Local Time was used for all the accident flight data and is indicated on all plots and tabular output.

1.11.3 FDR/CVR Correlation Analysis

A summary of the FDR/CVR correlation is set forth in Figures 9 and 10.

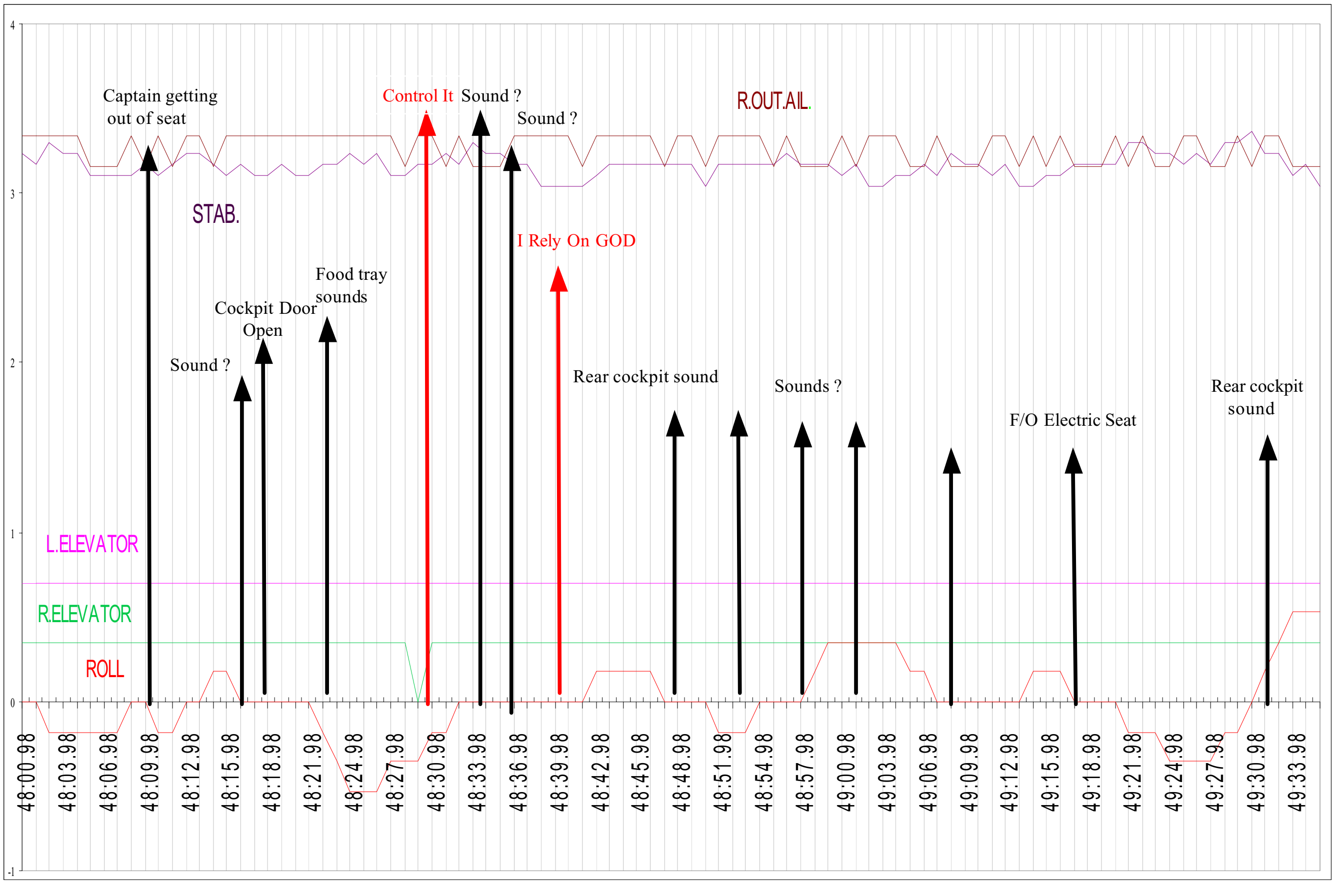

Figure 9 FDR/ CVR correlations

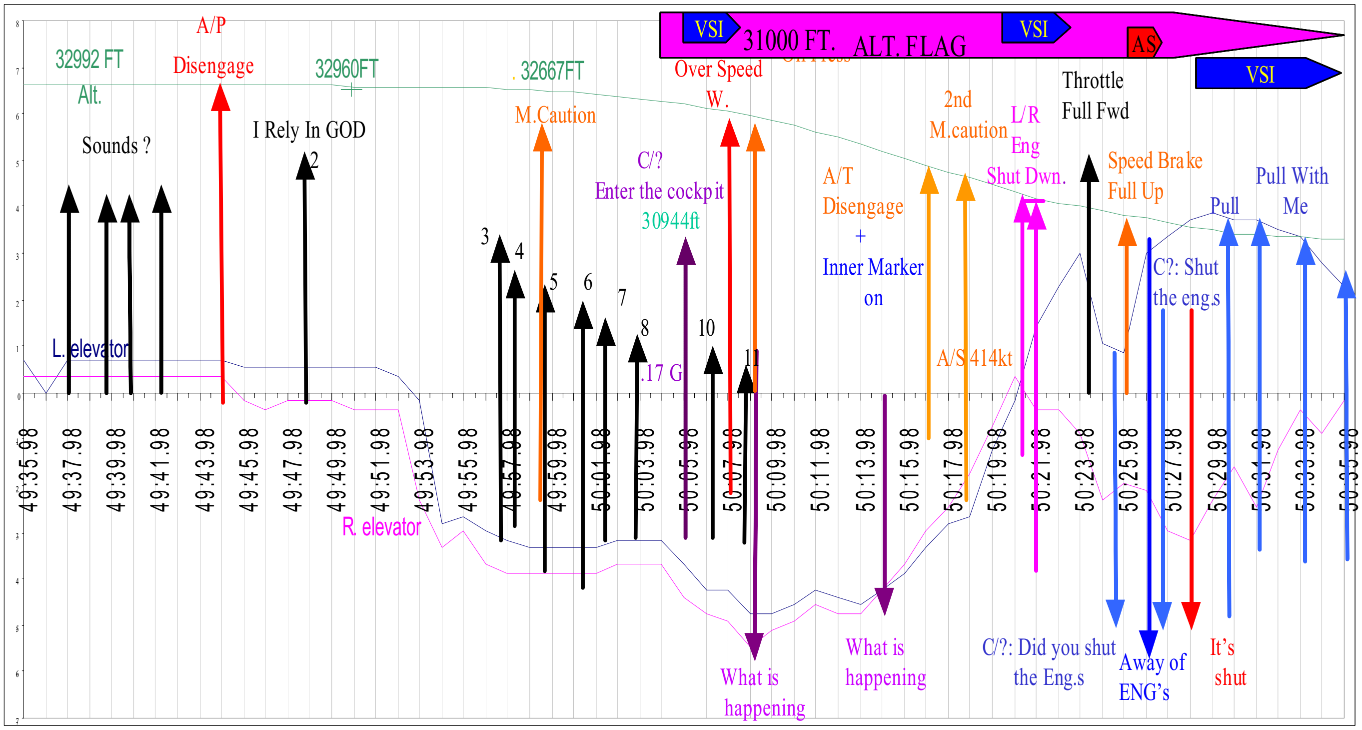

Figure 10 CVR/FDR correlations with additional cockpit indication information

1.12 Wreckage and Impact Information

1.12.1 Initial Rescue Operations

At 0209 the FAA's Area Manager In Charge (AMIC) notified the Air Force Rescue Coordination Center and the Coast Guard that Flight 990 was missing. This step was taken after initial efforts by the air traffic controller to contact Flight 990 were not successful. At 0216 AMIC notified the Eastern Region Operations Center (AEAROC) to try to contact EgyptAir. The contact number for EgyptAir was Alitalia operations at JFK, which was not answered. This led to a delay of almost two hours in notifying EgyptAir.

Meanwhile, the ZNY controller coordinated with Boston ARTCC to divert nearby to look for Flight 990. None of the contacted was able to locate the EgyptAir.

Later, units of the U.S. Coast Guard and the U.S. Navy were deployed in an effort to locate the crash site and to search for and recover any survivors. The crash site was located approximately 60 miles southeast of Nantucket Island. There were no survivors found and only a minimal amount of wreckage. The floating debris was generally small, fragmented pieces. This wreckage was recovered and later transported to a facility at the Quonset Point Naval Air Station near Newport, Rhode Island.

The initial search also included the use of underwater cameras and other detection equipment. Through the use of these assets, the wreckage of Flight 990 was located in approximately 220 feet of water. There were two debris fields about 1200 feet apart. The east (primary) wreckage site was located at 40º20’51”N, 69º45’24”W. A much smaller area of wreckage (west site) was located just to the northwest (at 293º) of this site at 40º20’57”N, 69º45’40”W.

As a result of the initial recovery efforts, the FDR and the CVR were located on November 9 and November 14, 1999 respectively. These recorders were delivered to the NTSB in Washington, D.C. for analysis.

1.12.2 Recovery Operations

1.12.2.1 Recovery Operations – December 12-21, 1999

As part of its investigation, the NTSB arranged for a recovery ship, the SMIT PIONEER, to provide the primary support and facilities for the recovery of the Flight 990 wreckage. The SMIT PIONEER left port in Rhode Island on December 12, 1999 and was deployed to the crash site with observers from the NTSB, FBI, and EgyptAir aboard. The recovery effort was concentrated in the main debris field. The ship returned to port on December 21, 1999.

According to the NTSB’s estimate, this recovery effort yielded approximately 70 percent of the wreckage by weight. As was the case with the debris that was recovered immediately after the accident, the wreckage consisted primarily of small, fragmented pieces. The largest intact piece or structure recovered was described by the NTSB as "a piece of structure almost 20 feet long." The wreckage was washed and placed into bins aboard the SMIT PIONEER. Thereafter, it was transported to Quonset Point.

1.12.2.2 Recovery Operations – March 28 – April 3, 2000

On March 3, 2000, the NTSB announced that it intended to undertake a second operation to recover additional wreckage from Flight 990. In particular, the NTSB advised that it would try to locate the left engine, which was believed to be in the western debris field. This recovery effort was estimated by the NTSB to take up to ten days.

At the conclusion of this phase of recovery, which lasted from March 29 to April 3, 2000, the NTSB stated that it had located and recovered the missing engine; the majority of the nose landing gear assembly; additional fuselage skin; horizontal stabilizer skin; portions of two wing panels; and some additional wreckage. In total, the NTSB estimated that 90 percent of the, by weight, was recovered. Again, the recovered parts were largely small and fragmented, except for the left engine and the nose landing gear assembly, which were substantially intact. This wreckage was also transported to the Quonset Point facility.

1.12.3 Wreckage Examination

From January 5-14, 2000 and on April 11, 2000, the NTSB Systems Group met at Quonset Point, Rhode Island during which time, they sorted and identified various components. The details of this identification process are set forth in the System Group chairman's Factual Report. In summary, the group identified wreckage from the longitudinal control system (including elevator actuators, bellcrank assemblies, and pogos), the lateral control system, the directional control system, the stabilizer control system, other flight control system components (including miscellaneous rods, tubes, and pulleys), the hydraulic system, the fuel system, the electrical system, the environmental control systems, the tail skid system, and various cockpit items (including parts of a control wheel and speedbrake handle). As the focus of this effort was on part identification, there was no substantial analysis of the parts that had been recovered.

From April 17-20, 2000, the Systems Group met at the Engineering Quality Analysis (EQA) laboratory at the Boeing facility in Seattle, Washington. The group performed external examinations and disassembled certain recovered items of the longitudinal control systems. The details of this examination are set forth in Addendum 2 of the Systems Group Chairman's Factual Report ("Teardown of Selected Longitudinal Control System Components") and are summarized under Tests and Research below. In addition, a detailed metallurgical analysis was performed at the NTSB laboratory in Washington, D.C. The details of this examination are set forth in the NTSB Materials Laboratory Factual Report.

1.13 Medical and Pathological Information

The accident site was located approximately 60 miles southeast of Nantucket Island, Massachusetts. Although relatively close to the coast of the United States, the location nevertheless prevented rescue vessels from reaching the scene for a few hours after the accident. After their arrival and during the subsequent search, no survivors were found.

During the course of the underwater search and the subsequent recovery operations, no intact bodies were recovered. The human remains that were recovered, including bones, were small, fragmented pieces which precluded any visual identification of the victim. Because of the nature and condition of the remains that were recovered, all identification was by forensic analysis and DNA testing undertaken by the Medical Examiner for the state of Rhode Island. As of May14, 2001, 128 of the victims had been identified.

1.14 Fire

There were no indications of an inflight fire. There was no evidence of fire at the impact site.

1.15 Survival Aspects

The accident was not survivable for either the passengers or the crew. The complete destruction of the airplane precluded an analysis of safety equipment or systems.

1.16 Tests and Research

During the course of the investigation, tests and research were conducted to analyze the possibility that the accident was attributable to a mechanical defect. This element of the investigation relied upon simulations and ground tests at Boeing and upon an analysis of certain components of the elevator system recovered from the crash site. The nature of the tests conducted is described below and the results are discussed in the ANALYSIS section.

1.16.1 Simulator Tests

A series of tests were conducted in the Boeing E-Cab. The first tests were conducted at the Boeing Corporation in Seattle, Washington on December 8-9, which was prior to the recovery of any significant wreckage. The purpose of these tests was to review the dive of EgyptAir 990 from 33,000 feet, its climb back to 24,000 feet, and its final dive into the ocean. These were based on FDR and radar data.

Four tasks were planned for this set of tests as follows:

1. Background simulation for the purpose of:
    a. Determining the control inputs necessary to drive the accident sequence.
    b. Verifying that the 's performance was consistent with the radar data.
    c. Validating/adjusting the simulator's aerodynamic database to achieve more accurate results.

2. Backdrive simulation for the purpose of:
    a. Having cockpit instruments and controls “replay” the accident.
    b. Providing a visual reference for FDR and radar derived data.
    c. Observing the timing of events, force levels on flight controls, and level of cockpit activity.
3. Backdrive simulation with pilot intervention for the purpose of:
    a. Allowing a participating test pilot to take control of the simulation at any point and attempt a recovery.
    b. Allowing a participating test pilot to experience the forces and workloads requested for recovery.
4. “Hand-flown” simulations for the purpose of:
    a. Allowing test pilots to experience the workload and force levels required to fly a zero “g” maneuver.
    b. Observing the workload and time required to restart the engines.
    c. Evaluating the handling characteristics of the   with reduced hydraulic power.

Although using the simulator allowed various tests to be conducted in a cost-effective manner, the simulator could not, and did not, accurately reproduce either the cockpit or certain flight characteristics of the accident airplane. Accordingly, the results of the simulator tests must be considered along with the following notes, limitations, and modifications:

- Simulator Important Notes
    1. The Background and Backdrive simulations are driven through climb to approximately 24,000 feet.
    2. The final descent to surface is not shown.
    3. The control column motion is based on FDR elevator position only until elevator split.
    4. After elevator split, the column motion is driven to match FDR pitch angles using symmetric elevators.

5. Column and wheel motions after the DFDR data ends are driven to match pitch and roll angles derived from radar; therefore, there is relatively large uncertainty.
6. The aerodynamic database of the simulator was modified to reflect the best engineering estimate of airplane performance at high Mach number.

- Simulator Limitations

  1. The cab is fixed-based, so motion is not available. With the exception of stick shaker, the physiological effects on the pilots due to stall, its buffeting characteristics, and g-loads are not modeled.
  2. The visual landscape is a featureless land with a visible horizon, rather than the dark, horizonless view at the time of the accident.
  3. No Mach or stall buffet is modeled.
  4. Numerous status messages are displayed erroneously on EICAS.
  5. There are no metric displays for fuel quantity and fuel flow.
  6. There are no thrust reverser isolation lights.
  7. There is no stand-by compass.
  8. Wind and engine noise are not modeled.

- Modeling Limitations

  1. There is only one control loader. The control columns and elevators can only be moved symmetrically in the cab. Split operation between the two is not available.
  2. The simulator model accounts for hydraulic power generation (for example, from windmilling engines) independently from hydraulic power usage (for example, flight control movement).
  3. There is no hydraulic decay model or elevator blowdown model that simulates the decay of hydraulic pressure as the engines windmill and speed decreases.
  4. The asymmetry and unsteady aerodynamics of stalls are not accurately represented.
  5. The low oil pressure light does not illuminate.

6. The E-Cab's Air Data Computer calibration has not been verified at Mach numbers in excess of 0.86.

7. All the simulator activities are based on the assumption that all the systems were operating normally, without any system malfunction.

8. The primary altimeters on the E-Cab display "off flags" during excessive descent rates (normal operation).

- Back-drive Scenario Limitations

1. For back-drive simulations, the throttle levers can only be driven at autopilot rate (approximately 10 deg/sec), although the engine parameters (EPR, NI, N2) are driven at the rates recorded on the flight data recorder.

2. During back-drive, the speed brakes must be manually armed.

- Modifications Carried Out on the E-Cab Simulator

Several parameters of aerodynamic data were modified for flight conditions above a Mach number of 0.91. The parameters that were modified were lift coefficient, pitching moment coefficient, drag coefficient of the wing-body, spoiler blowdown characteristics, spoiler effect on lift coefficient and spoiler effect on pitching moment coefficients.

- Additional Important Limitation

The following statement is extracted from the NTSB performance Group Chairman's performance study, Exhibit 13, Addendum 2:

> An exact match between the simulator and recorded elevator positions would be unexpected because of uncertainties in the flight condition and mathematical models, and because the recorded elevator positions are not necessarily the exact elevator positions experienced in flight. The elevator position signal is filtered before being recorded, so that signals from quick, abrupt movements in the surfaces may not be apparent in the recorded data.

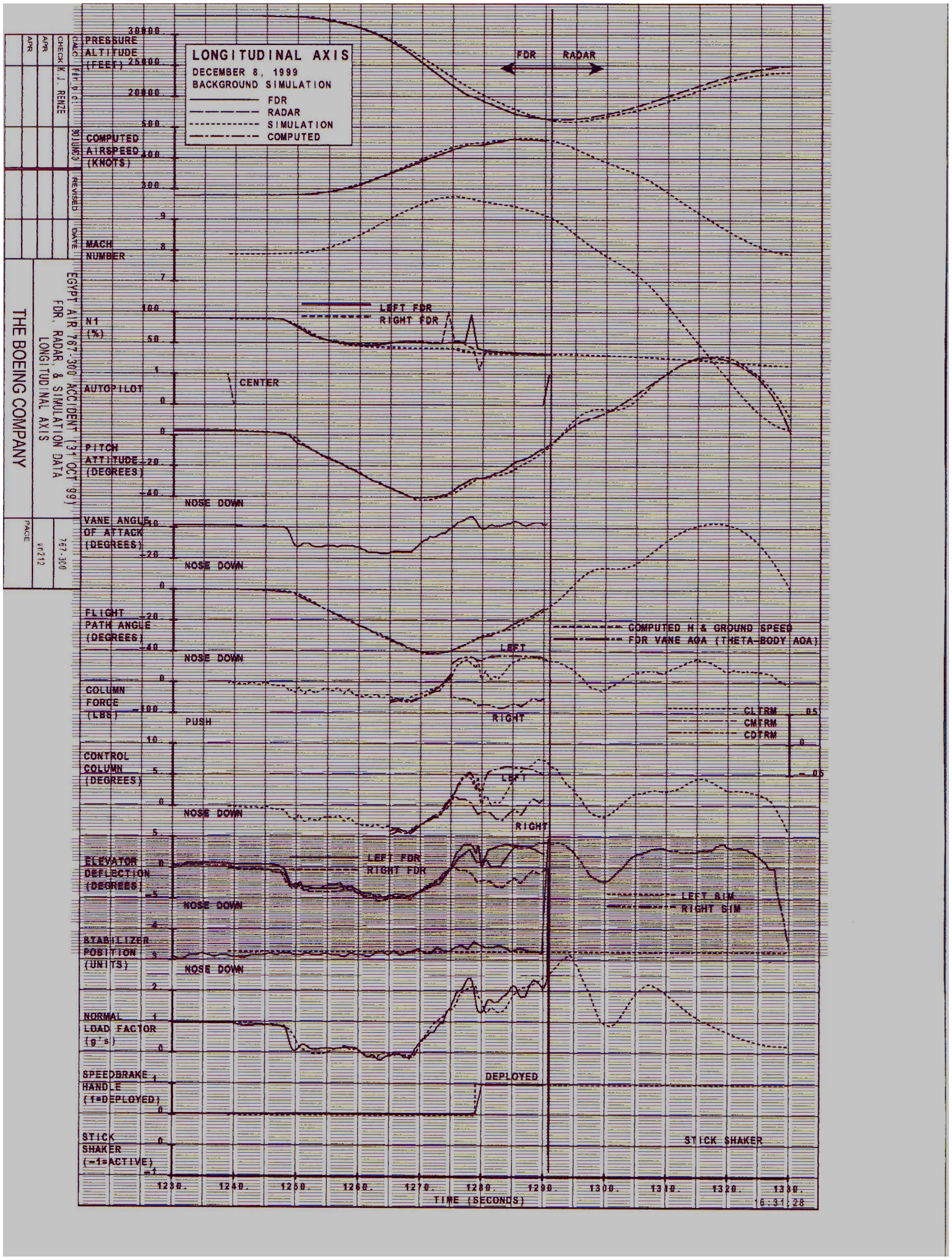

Figure 11 EgyptAir 990, E-Cab Results, Boeing, Seattle, Dec 1999, Longitudinal Axis

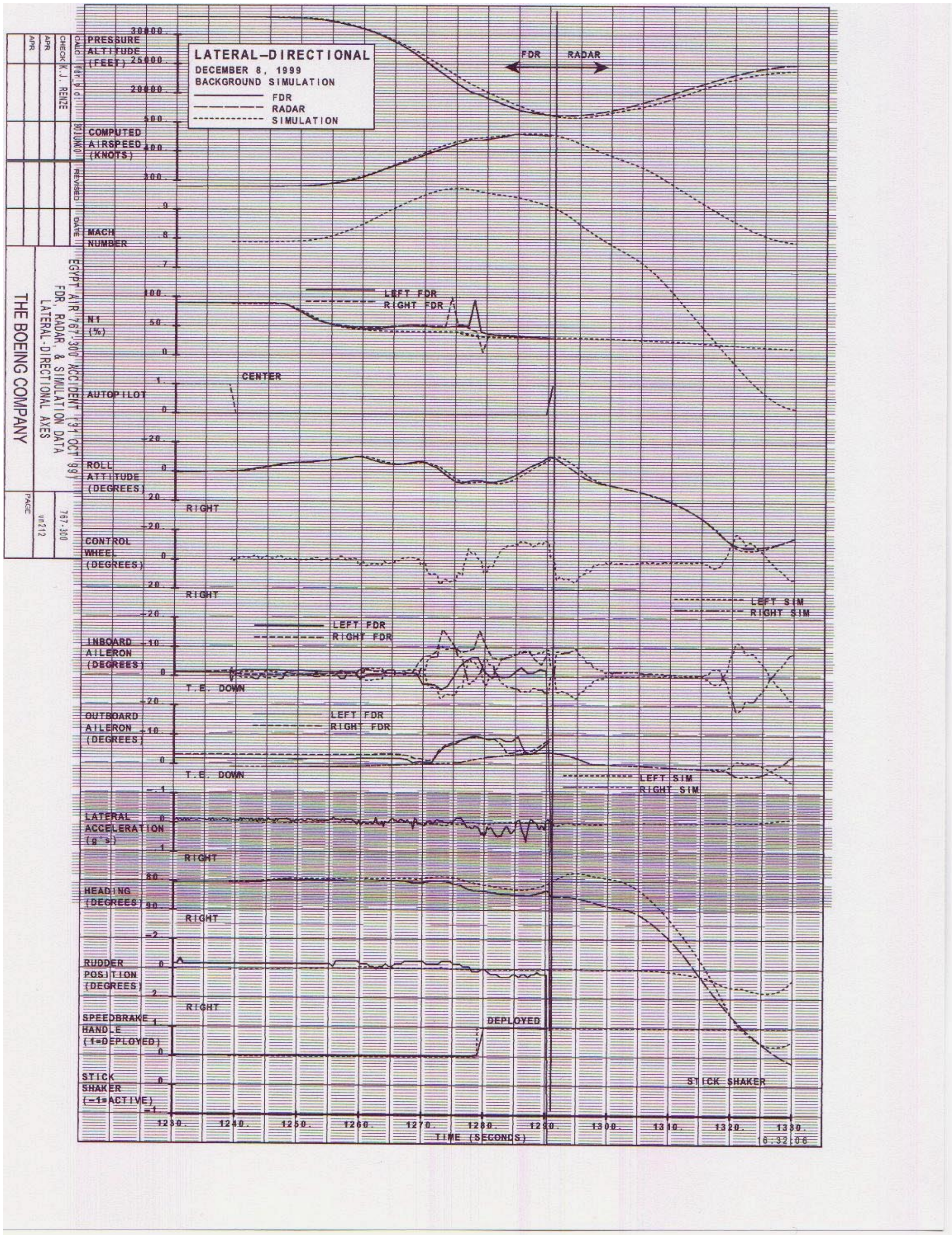

Figure 12 EgyptAir 990, E-Cab Results, Boeing, Seattle, Dec 1999, Lateral Axis

The second E-Cab simulations took place on March 30-31, 2000 at the Boeing facilities in Seattle, Washington. The tests on the E-Cab were intended to address two areas: human performance and systems (in particular, elevator malfunctions).

- Cab Tests Addressing Human Performance

  These tests were intended to provide information on the final flight maneuvers through the following:

  - Background Simulation
    - To determine the control inputs required to drive the desired events.
  - Backdrive Simulation with and without pilot interaction
    - To evaluate human performance synchronized with the CVR and DFDR.
  - Backdrive "Split Elevator" Simulations
    - To provide a replay of the flight deck instruments and controls with and without an attempt to match the CVR.
    - To experience the timing of events, control force levels with split elevators, and sounds on the flight deck
    - To allow the pilot to take control of the A/C during the elevator split and experience the workload and control forces required.
- Cab Tests Addressing Elevator Malfunctions

  These tests attempted to assess the behavior of the B-767-300ER with various elevator malfunctions imposed. The flight controls model contained within the simulation of the 767-300ER was modified in order to support simulator testing of various elevator failure scenarios. The response of the simulator was shown with each of the following scenarios:

  - ☐ The control valve jams trailing edge down (TED) on two separate PCA's, on the same elevator surface, at the same time, causing a TED hardover of that surface.

    Simulation Response

    - The failed elevator surface moves to a TED position equivalent to 80% of the single PCU blowdown limit, and then tracks this limit position as it varies with changes in flight condition.
    - A constant force bias of 30 pounds will be applied to the control column in the forward direction. This will cause a corresponding shift in the column position and the non-failed elevator surface as the feel and centering unit reacts to the force bias. Pilot control of the non-failed elevator through the column will be unaffected, except that the normal feel force profile will be altered by the additional force bias. If the flight condition exceeds an aerodynamic impact pressure of 400 psi, the force bias will be gradually reduced to ensure that the "hands-off" position of the non-failed elevator surface does not exceed that of the failed elevator surface. The non-failed elevator surface will continue to respond to column inputs normally.

- ☐ The input linkage to two different PCA's disconnects, on the same elevator surface, at the same time (one could be latent), causing a TED hardover of that surface.

  Simulation Response

    - The failed elevator surface moves to a TED position equivalent to 80% of the single PCU blowdown limit, and then tracks this limit position as it varies with changes in flight condition.
    - The normal feel force profile for the column will remain unchanged. Pilot control of the non-failed elevator through the column will be unaffected. The non-failed elevator surface will continue to respond to column inputs normally.

- ☐ The control valve jams TED on one PCU, and the input linkage to another PCU disconnects (could be latent), on the same elevator surface, at the same time, causing a TED hardover of that surface.

  Simulation Response

    - The failed elevator surface moves to a TED position equivalent to 80% of the single PCU blowdown limit, and then tracks this limit position as it varies with changes in flight condition.
    - Constant force bias of 15 pounds will be applied to the column in the forward direction. This will cause a corresponding shift in the column

> position and the non-failed elevator surface, as the feel and centering unit reacts to the force bias. Pilot control of the non-failed elevator through the column will be unaffected, except that the normal feel force profile will be altered by the additional force bias. The non-failed elevator surface will continue to respond to column inputs normally.

As with the December 1999 simulations, there were also a number of simulator characteristics that limited the accuracy of the simulations of conditions on the accident airplane. The following notes, limitations, and modifications are in addition to those noted in connection with the December 1999 simulations:

- Simulator notes:
  - The E-Cab area contains a mockup of the aft bulkhead of the flight deck including the entry door, adjoining lavatory, and the passage way between them. Two jump seats are also located at the rear of the flight deck.
- Modeling Limitations/modification:
  - Actual airplane behavior at Mach numbers above 0.91 is not included in the simulator software. Instead, the aerodynamic database is extrapolated from Mach 0.91 to 0.98.
  - Simulation modifications were made to lift, drag, and pitching moment parameters at speeds beyond the dive Mach number of 0.91.
  - A “small artificial ‘delta Cm trim’ was introduced.”
  - Differential elevator displacement was included in the software description of the system; however, the force feedback to the columns was not modeled. The elevator column override mechanism is not included in the simulator because there is only one control loader.
  - After the end of the FDR data, it is assumed that both elevators were available and were operating normally and symmetrically.
  - The Backdrive simulations with pilot intervention are designed for the pilot to take control during the elevator split.

- Before elevator split, the left and right computed column forces are based on the average of the recorded left and right FDR elevator angles. After the elevator split, they are based on their respective FDR elevator angles.

- The airspeed and altitude that are recorded on the FDR are derived from the airplane's Air Data Computer (ADC), but the calibration of the ADC has not been verified for Mach numbers above 0.91 or for calibrated airspeeds above 420 knots.

- Electrical stabilizer trim using the manual electric trim switch on the control wheel is not available after the fuel cuts.

- The column cutout switches do not inhibit stabilizer trim when the columns are split.

- The simulator does not support a dual actuator input failure condition with the autopilot engaged.

- The primary failure effects, including elevator surface hardover and application of column force bias, occur instantaneously when the failure is introduced; normal PCA rate limits and air load damping effects are ignored.

- To simplify implementation of the PCA Input Jam cases, the PCA pogo force bias is applied at the column rather than at the aft quadrant. This will result in a slight increase in actual column position bias due to the cable stretch effect.

- For the Dual PCA Input Jam case, the adjustment to the applied force bias for flight conditions with aerodynamic impact pressure greater than 400 psi is approximate and is only intended to provide a good match to the actual response for a specific flight condition.

- For the Dual PCA Input Jam case, the effect of PCA input pogo travel limits and shear outs are not modeled in the simulation.

- For the Dual PCA Input Jam case, the change in feel force gradient due to breakout effects above 70 pounds at the column on the side opposite the failed elevator are not modeled in the simulation.

- For the Dual PCA Input Disconnect case, the additional force gradient introduced by the slave cable lost motion device are not modeled in the simulation.

- Limitations on elevator control system asymmetry and differential elevator travel are not modeled in the simulation.

- Important Note

Appendix D of the NTSB performance Group Chairman’s performance study, Exhibit 13, Addendum 2, stated that Boeing review of the March 2000 Performance Group E-Cab simulation data revealed two anomalies (an offset and a discontinuity) with respect to piloted elevator response. The error sources were identified in the flight controls model and a fix was implemented. The elevator offset error was caused by an inconsistent gain between the E-Cab control forces and the corresponding elevator command. The elevator discontinuity was caused by a bookkeeping error between the aft pogo breakout force contribution to cable stretch, the aft quadrant column position, and the feel unit force.

Simulation Scenarios from the March 2000 demonstration were repeated by Boeing's Operation Group in June 2000. The E-Cab simulation data recorded in June 2000 are presented in the said Appendix.

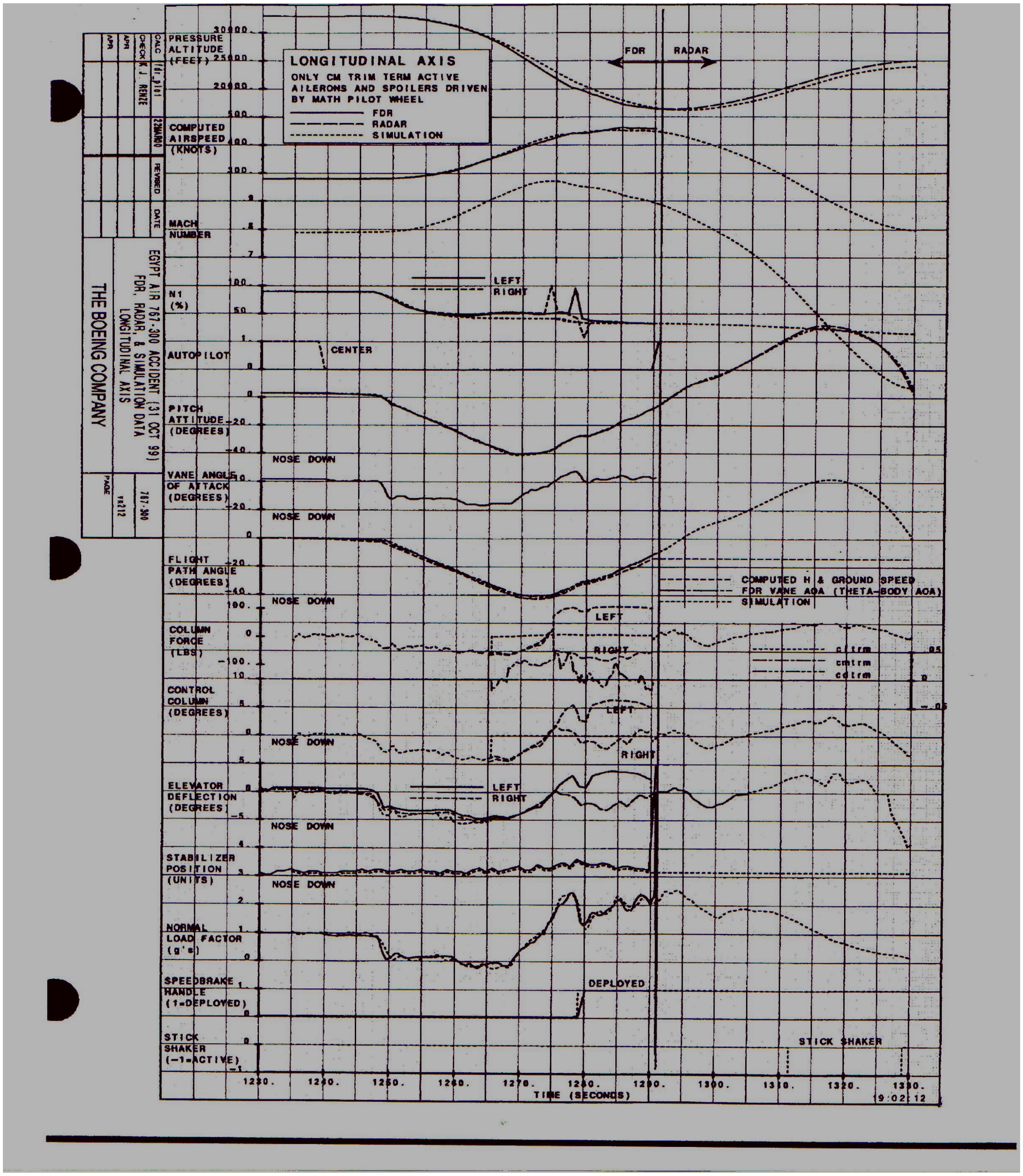

Figure 13 EgyptAir 990, E-Cab Results, Boeing, Seattle, March 2000, Longitudinal Axis

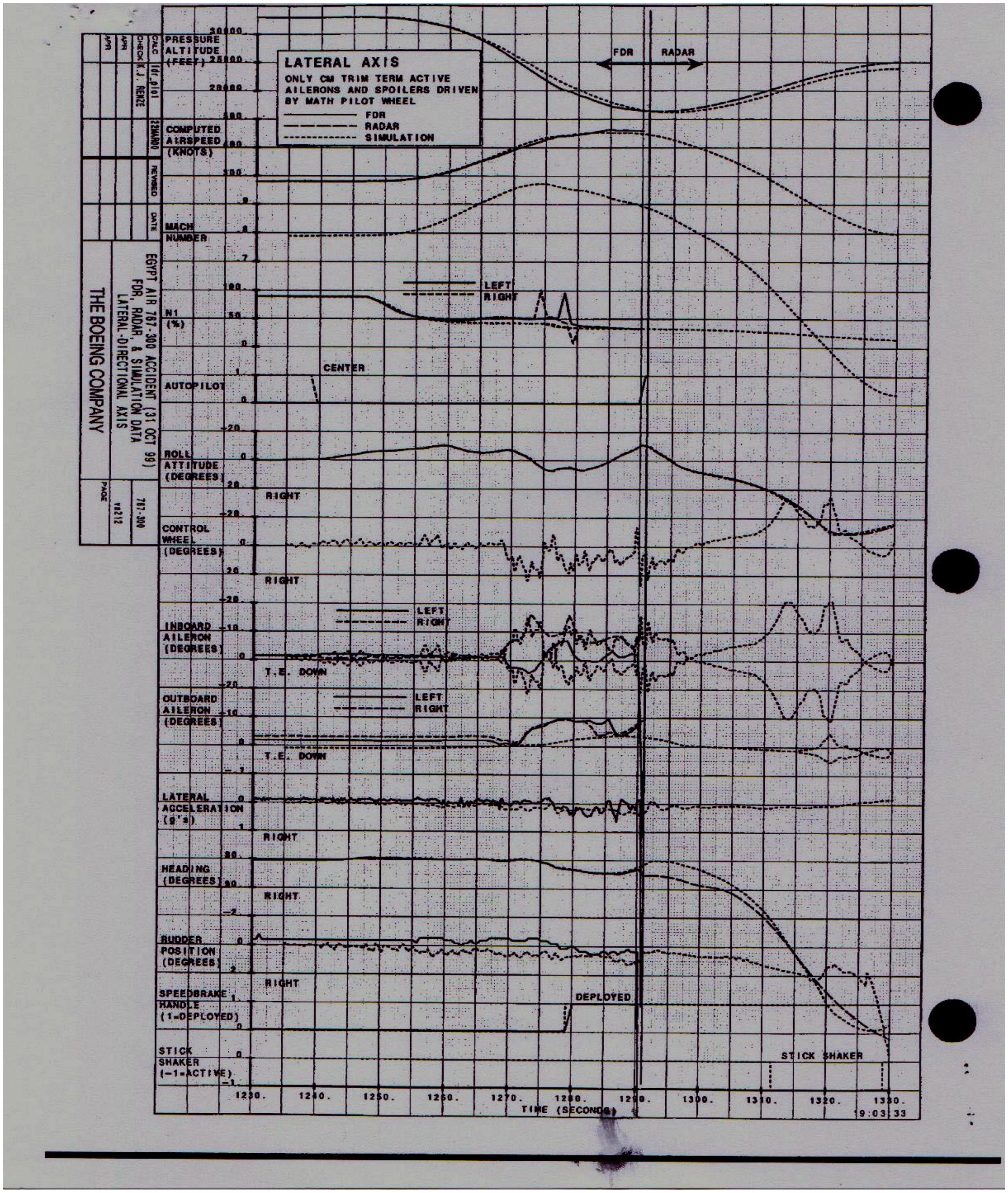

Figure 14 EgyptAir 990, E-Cab Results, Boeing, Seattle, March 2000, Lateral Axis

1.16.2 Ground Tests

1. **Ground tests – December 9, 1999**

In addition to the E-Cab simulator tests, investigators participated in a ground test on a Boeing 767-400 flight test airplane. During this test, the participants experienced the column forces required to split the left and right control columns while on the ground. These tests used an actual B-767, modified as necessary, depending upon the test objective.

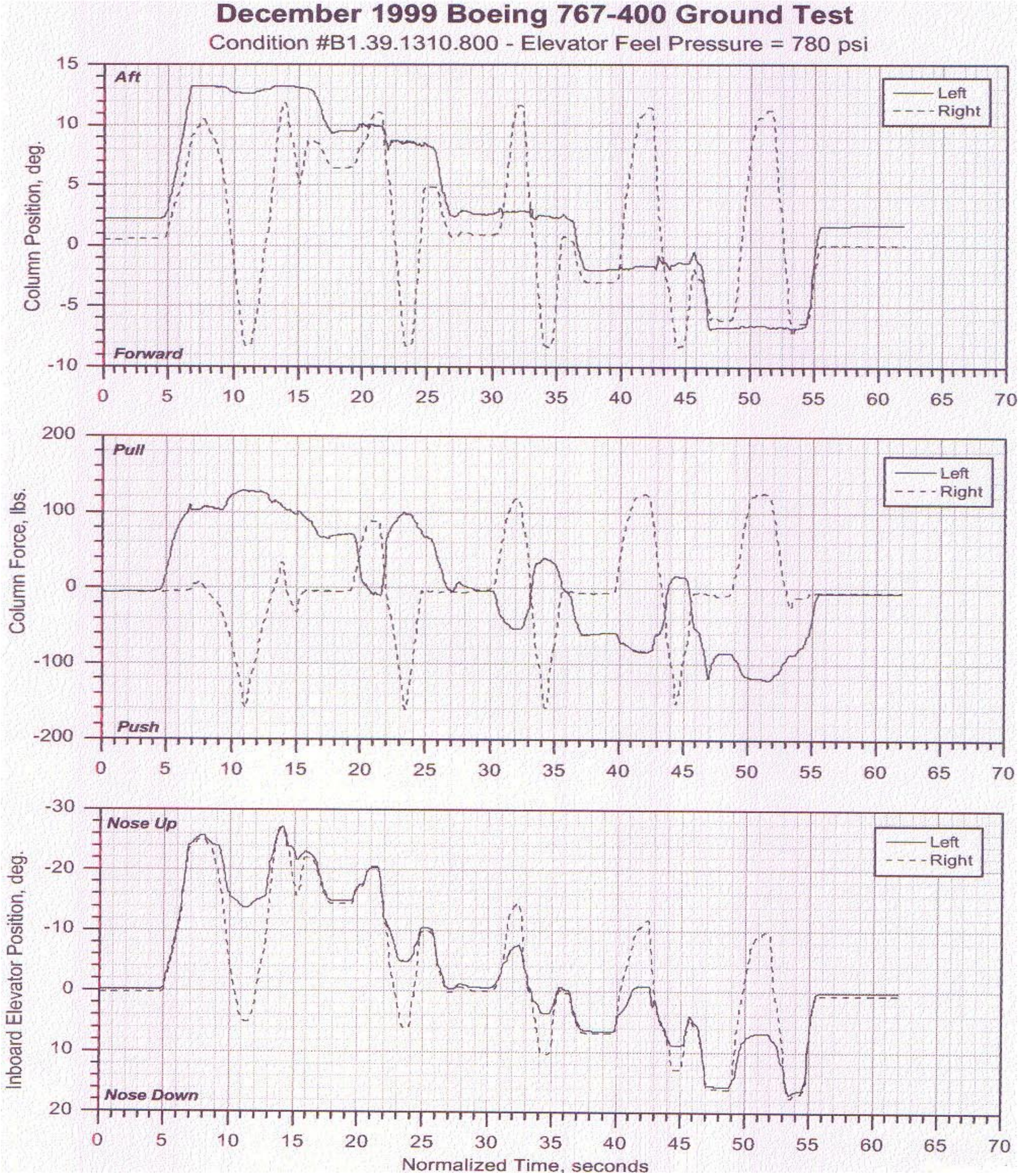

Figure 15 Ground test data, December 1999 (Elevator feel pressure 780 psi)

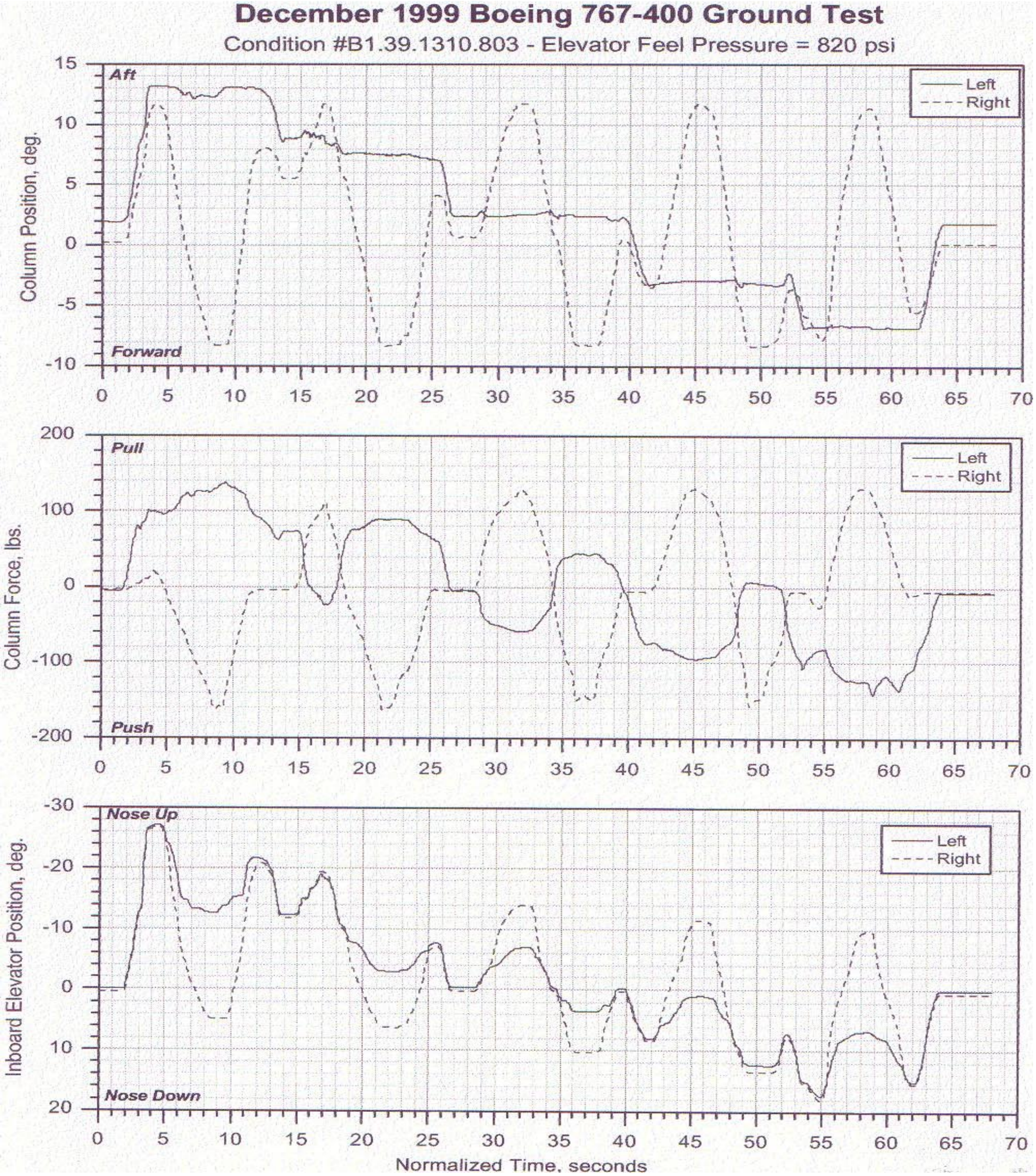

Figure 16 Ground test data, December 1999 (Elevator feel pressure 820 psi)

2. Ground tests – March 31, 2000 and April 20, 2000

Two more ground tests were conducted to investigate the effects of different failure conditions on the elevator system. The scenarios evaluated were:

- The failure of a single elevator PCA (disconnection).
- The failure of a second elevator PCA on the same side (disconnection).
- Single elevator PCA jam commanding elevator down deflection.
- Second elevator PCA jam on the same side commanding elevator down deflection.
- Single elevator PCA disconnected, followed by the jam of a second elevator PCA on the same side commanding elevator down deflection.

The evaluation also included performing elevator control column sweeps from the right and left cockpit positions with base feel pressure and 770 psi feel pressure.

These ground tests were limited because:

A. Boeing failed to record the temperature that could allow adjustment for force bias.

B. The tests only used two feel-pressure settings.

C. The tests failed to account for any back-driving force resulting from the particular test failure scenario.

D. The tests failed to account for the effect of airloads on the elevator surfaces as the test was performed in a stationary condition.

1.16.3 Detailed Examination of Elevator PCA's

As noted above, there was a detailed investigation of a possible jammed PCA in the right elevator (outboard PCA). All the damage that was found inside the manifold of the servo valve was unique among all the recovered elevator components

The following elevator system components were recovered:

- Four elevator PCA's out of six, two of them with the manifold assembly connected to the PCA.
- Five bellcranks out of six, three of them from the right elevator.

- Five pogos out of six, two of them from the right elevator.
- One intact manifold housing (MH #1), one small manifold part (MH #2) and two manifold parts (MH #3 & MH #4) together make a complete manifold.
- Two feel computers.

The inspection of the elevator components was done in two phases. Phase 1 was a preliminary inspection conducted in the EQA laboratory at Boeing Facility, Seattle, Washington. Phase 2 was a more thorough inspection of selected elevator components in the NTSB Materials Laboratory. The results of Phase 1 and Phase 2 revealed the following facts:

1. PCA #1:
    a. The identification plate was missing, so the PCA position could not be identified**.**
    b. The piston extension was 3.65 inches between the snubbing gland and the runout area of the piston rod end.
    c. The servo valve manifold was detached from the actuator assembly.
    d. The piston rod had a visible bend.
2. PCA #2:
    a. The identification plate is missing, so the PCA position could not be identified.
    b. The piston extension was 2.2 inches between the snubbing gland and the runout area of the piston rod end.
    c. The servo valve manifold was detached from the actuator assembly.
    d. The piston rod had a visible bend.
3. PCA #3 (see Figure 19)
    a. The PCA serial number is 638 (in the right elevator, outboard position).

b. The piston extension was 0.28 inches between the snubbing gland and the runout area of the piston rod end (the PCA was almost fully retracted).

c. The four bolts that connect the manifold to the PCA were sheared, but the manifold was still connected to the piston through the summing lever.

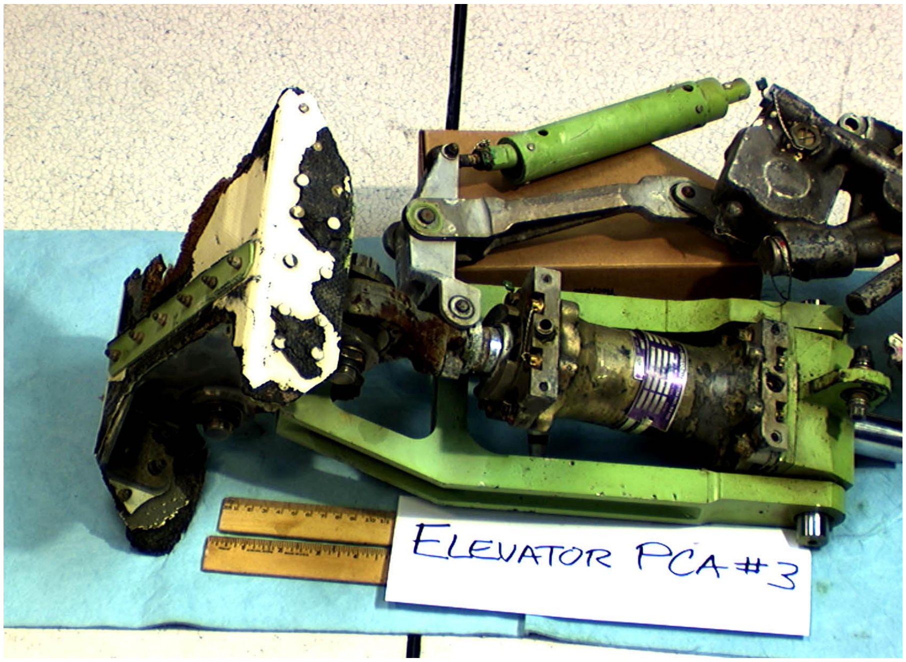

Figure 17: Recovered PCA # 3

d. Upon removal, the piston appeared straight.

e. The rolled pin that connects the servo slide to the spring guide was sheared as if the slide moved through the spring guide.

f. The bias spring was found rolled over the guide with one coil according to the system group chairman EQA Field Notes and two coils according to the NTSB Material Laboratory Factual Report and the CT X-ray photo.

g. The spring guide had some markings: on the face with the smaller diameter that were caused by the slide impacting the guide several times after shearing of the pin, two markings on the outer diameter of the guide caused by the bias spring and a rub mark adjacent to the edge of the pin hole caused by the bias spring. This is according to the NTSB Material Laboratory Factual Report.

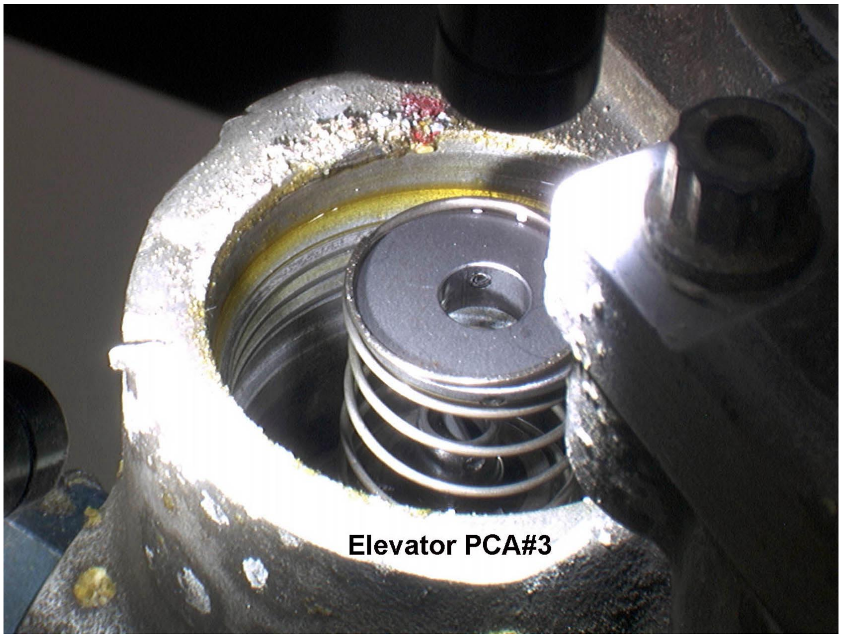

Figure 18 anomalies in PCA # 3

h. The servo slide had some scratches, aligned with the rolled pin position, caused by the sheared pin. The shear direction was as if the slide moved through the sleeve for a maximum distance of 0.28 inch. Also, the input hole in the slide had a heavy wear mark in the direction of commanding the PCA to extend (nose up). This is mentioned in the NTSB Material Laboratory Factual Report (report number 00-071).

i. The servo cap contained some corrosion pits and some particles. The chemical composition of one of the particles was consistent with the chemical composition of the spring guide and another particle was consistent with the chemical composition of the servo cap. This is mentioned in to the NTSB Material Laboratory Factual Report (report number 00-071).

j. The servo sleeve inspection revealed some circumferential bands of corrosion stains on the sleeve internal surface.

5. PCA #4:

a. The PCA serial number is 1778 (in the right elevator, center position) and was still attached, when recovered, to the horizontal stabilizer rear spar.

b. The piston extension was not measured, but the photos showed that the piston was almost at a neutral position.

c. The manifold was still attached to the cylinder.

    d. Upon removal, the piston appeared straight.

    e. All the parts inside the manifold were intact and in their proper position.

5. MH #1:

    a. There was no identification plate, so MH #1 position could not be identified.

    b. The shear pin, the spring, and the spring guide were intact and in their proper positions.

    c. Inspection revealed corrosion damage on the slide near the bias spring side.

6. MH#2:

    a. There was no identification plate, so MH #2 position could not be identified.

    b. This piece contained the input side of a servo valve only, and it is fractured from an un-recovered manifold.

7. MH #3 (Figure 17):

    a. There was no identification plate, so MH #3 position could not be identified.

    b. The shear pin, the spring, and the spring guide were intact and in their proper positions.

    c. The input section was broken off.

    d. The fracture surface on MH #3 matched the fracture surface of MH #4.

    e. The sleeve and slide were heavily corroded.

    f. No significant marks were found on any of the parts.

8. MH #4 (Figure 17):

    a. There was no identification plate, so MH #4 position could not be identified.

    b. This piece contained the input side of a servo valve only.

    c. The fracture surface on MH #4 matched the fracture surface of MH #3.

d. A white Teflon washer was missing beneath the input crank.

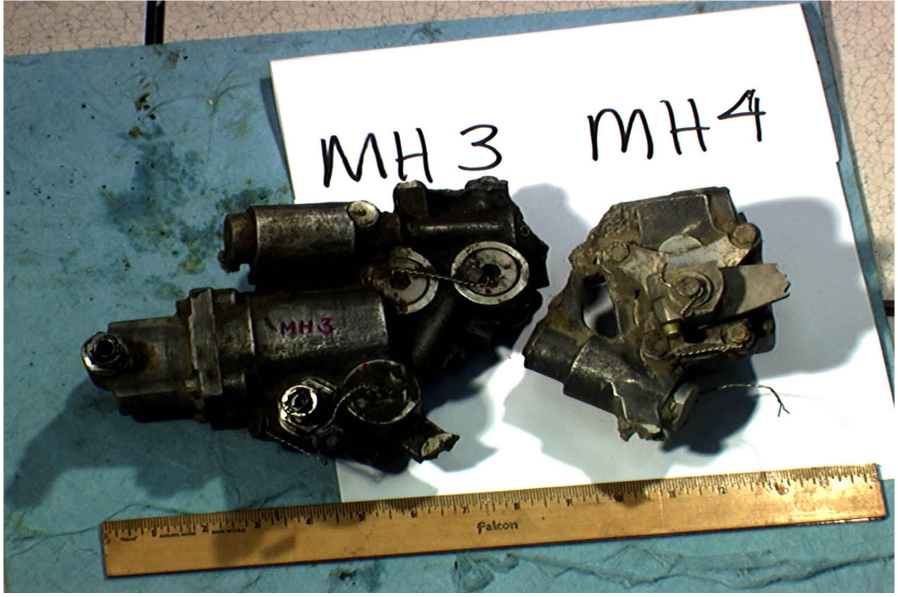

Figure 19: Manifold Housing #3 and #4

9. Bellcrank #1:

    a. This bellcrank was from the left elevator, but could not be identified to a specific position.

    b. The rivets were sheared as if the bellcrank arms were moving to a higher relative angle as mentioned in the NTSB Material Laboratory Factual Report.

10. Bellcrank #2:

    a. This bellcrank was from the left elevator, but could not be identified to a specific position.

    b. The rivets were sheared as if the bellcrank arms were moving to a higher relative angle as mentioned in the NTSB Material Laboratory Factual Report.

11. Bellcrank #3:

    a. This bellcrank was from the right elevator outboard position.

    b. The rivets were sheared as if the bellcrank arms were moving to a lower relative angle as mentioned in the NTSB Material Laboratory Factual Report.

    c. The rivets sheared flush with the recess in the arm that contains the shaft.

12. Bellcrank #4:

    a. This bellcrank was from the right elevator center position.

    b. The rivets were sheared as if the bellcrank arms were moving to a lower relative angle as mentioned in the NTSB Material Laboratory Factual Report.

    c. The rivets sheared flush with the recess in the arm that contains the shaft.

13. Bellcrank #5:

    a. This bellcrank was from the right elevator inboard position.

    b. The rivets were sheared as if the bellcrank arms were moving to a higher relative angle as mentioned in the NTSB Material Laboratory Factual Report.

    c. One of the rivets sheared flush with the recess surface while the other rivet's shear plane was in line with the bearing surface. The scanning electron microscope (SEM) examination revealed the presence of a circumferential crack in the rivet that propagated flush with the surface of the recess in the bellcrank arm.

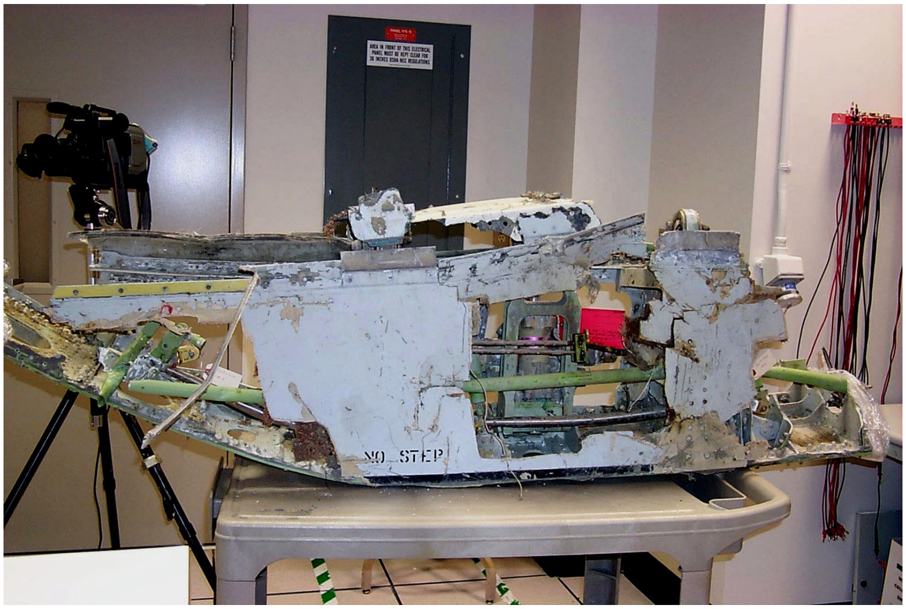

Figure 20 Right elevator center PCA attached to stabilizer rear spar

14. Input push-pull rods for the right elevator:

    a. All three rods were found to be deformed by bending. The most severe deformation was noted on the push-pull rod between bellcrank #3 and bellcrank #4. The push-pull rod between the bellcrank #4 and bellcrank #5 was subjected to the smallest amount of deformation. As mentioned in the NTSB Material Laboratory Factual Report.

1.17 Other Information

1.17.1 The Boeing 767 Elevator Control System Discrepancies

Over the past six years, there have been a number of reports of elevator system discrepancy and bellcrank rivet shears in the Boeing 767 elevator control system. Bellcranks rivets are designed to shear in case of PCA jam to prevent jamming of the whole elevator control system.

The Egyptian Investigation Team (EIT) reviewed the FAA Service Difficulty Reports (SDR's) and any other reports/letters concerning any Boeing767 elevator system discrepancy and discovered the following information.

1. FAA Service Difficulty Reports (SDR's)

    a. On September 12, 1994, United Airlines reported that a B767-300 airplane (airplane serial number: 27159) "experienced a frozen elevator condition (during descending through 11,000 feet) which took 30 pounds forward pressure to pop the elevator free". Post landing inspection revealed no discrepancies were found with the elevator control system.

    b. On June 20, 1996, the same airplane reported the following "unable to hold altitude at 10,000 feet on autopilot which was disconnected and the elevator was stiff. After 5 to 10 minutes of using stabilizer trim, while pushing up and down on the control column, something let go at 4,000 feet and the airplane flew normal since". Post landing inspection, once more, revealed no discrepancies in the elevator control system.

2. Other Reported Incidents

    a. On late February 2000, during a preflight check on an AeroMexico Boeing 767, airline personnel noted that the left elevator was drooping. The resulting inspection and examination of the elevator bellcrank linkage disclosed that two of the bellcranks on the same elevator side (the left side) had sheared rivets. The airplane had flown for two weeks and about 77 hours since its last C-check during which the left elevator center PCA was replaced. Boeing's letter on March 15, 2000 stated that, "the elevator PCA bellcrank shear rivets were designed as a back-up to the elevator

> PCA pogo and will shear in the case of a jammed elevator PCA and a jammed elevator PCA pogo." On July 20, 2000, Boeing sent a letter to all 767 customers advising them of the possibility that the elevator single system hydraulic test may not detect a sheared bellcrank rivet and that the Federal Aviation Administration (FAA) planned to release an Immediate Adoptive Airworthiness directive (AD) concerning this issue.

1.17.2 Safety Issue

On June 4, 2000, the ECAA submitted a letter to the FAA concerning the "Level of Redundancy in the B767 Elevator Actuator System." In this letter, the ECAA stated that "the recently reported shear-outs in more than one elevator bell crank found weeks after any testing of the elevator system indicates that the 400-hour interval for conducting the prescribed special hydraulic maintenance check is inadequate to determine potential and double actuator faults in the elevator system." The ECAA proposed the following to the FAA:

a. Require a cockpit indication in the Boeing 767 that will alert the flight crew to a condition of abnormal PCA operation wherein a single fault in the elevator could result in uncommanded elevator movement.

b. Review the Boeing 767 elevator control system design and conduct further examination of the causes of the reported discrepancies found in the elevator actuator bell crank, and;

c. In conjunction with The Boeing Company develop cockpit crew procedures that will aid the crew during flight in identifying, isolating and negating an uncommanded elevator hard over condition.

1.17.3 Relevant FAA Airworthiness Directives

On August 25, 2000, the FAA issued AD 2000-17-05 to all Boeing 767 operators to perform a one-time functional check of the shear rivets in all six elevator PCA's bellcrank assemblies to determine the condition of the shear rivets. This AD stated, "This action is intended to address the identified unsafe condition." This AD validated the safety issues outlined by the Egyptian Civil Aviation Authority to the FAA on June 4, 2000.

On March 5, 2001, the FAA issued a second AD 2001-04-09 to mandate the functional check of the bellcranks' rivets to be every 400 flying hours.

1.17.4 Boeing 767 Fleet Team Conference

During a Boeing 767 Fleet Team Conference (held in Seattle, Washington during the period of October 31 to November 1, 2000), Boeing announced the results of AD 2000-17-05 and Service Bulletin 767-27A0166 which required inspection of the elevator bellcranks. The resulting inspection revealed that there was two bellcranks sheared, 55 partially yielded bellcranks, and 136 bellcranks with not fully reamed rivets as of October 27, 2000. The cause of these bellcrank failures is still under investigation. Boeing stated that it intended to adopt the following plan:

a) Perform a flight test to examine in-flight loads through the bellcranks.

b) Contact airlines to evaluate potential causes of bellcrank failures.

c) Develop maintenance procedures to detect gross mis-rig caused by yielded bellcranks.

d) Consider potential system design changes.

1.17.5 Recent Elevator Discrepancy Reports

The following discrepancies are still under investigation by the FAA, NTSB and Boeing:

1. In early March 2001, Gulf Air reported an elevator droop during a pre-flight inspection due to a sheared bellcrank on one of its Boeing 767 airplanes.
2. On March 27, 2001, American Airlines reported that one of its B767-300 experienced pitch control difficulties when descending through 6,000 feet on approach to Paris, France. Post-incident evaluation of the FDR confirmed that one of the elevators was frozen (believed to be the right elevator) in response to both autopilot and manual inputs, this event was described in the NTSB letter to the ECAA on April 19, 2001 as a binding of

the elevator aft quadrant. The pilots used the stabilizer trim to land the airplane. On the ground, the crew applied a higher force on the control column to break the elevator free. The post-landing inspection also revealed no discrepancies in the elevator system and the airplane was ferried back to Dallas, Texas.

1.18 New Investigative Techniques

None.

2.0 ANALYSIS

2.1 Analysis Overview

The analysis of the EgyptAir 990 accident is presented in this document. It is divided into three parts. In Section 2.2, thorough analyses of the human factors involved in this accident investigation are presented. The results of the human factors analysis ruled out that the RFO dove the airplane into the ocean. In Section 2.3, the possibility of a mechanical failure as being a possible cause of the accident is explored. The results of the analysis show that a dual PCA failure is consistent with the known and predicted behavior of the airplane and all of the recorded data concerning the accident. In Section 2.4, communications between EgyptAir 990 and Air Traffic Control (ATC) and the recorded ATC radar data are analyzed. This analysis leads to a depiction of the flight path and a determination of the location at which the left engine departed the airplane.

The results of the analysis of the EgyptAir 990 accident show that a dual PCA failure is consistent with all of the available data on the accident. Although the evidence of a dual PCA failure is not conclusive, it must be considered as a possible, and highly likely, cause of the accident.

2.2 Human Performance Analysis

2.2.1 Overview

A thorough analysis of the human factors involved in the EgyptAir Flight 990 accident investigation are presented in the following sections. Among the sources used for the analysis are the CVR and the FDR data. The overall conclusion of the human factors investigation ruled out the probability that the RFO dove the airplane in the ocean. Among the information considered was the psychiatric analysis of the First Officer by Dr.

Adel Fouad, M.R.C. Psych. London, and Consultant Psychiatrist. This analysis concluded that there is no psychiatric evidence that First Officer El Batouty was suffering from depressive disorder or bipolar illness. Also there is no evidence of schizophrenia, alcohol abuse or any psychotic condition.

A speech analysis of the most relevant phrases (like the phrase “Control it,” and “Tawakkalt Ala Allah”) and a sound spectrum analysis for most important sounds was also conducted. This analysis showed that there was no evidence of fight or struggle among the crewmembers during the dive, on the contrary, the evidence indicated a crew cooperating to recover airplane control. Analysis results also support the conclusion that there were more than two persons in the cockpit, especially at the start of the dive where there were repetitive general inquiry phrases and at the time the engines were shut down.

The analysis of the results of the simulator tests conducted at Boeing, on March 2000 also supports this conclusion.

2.2.2 CVR-FDR ANALYSIS

- Analysis of the Collected data from the CVR and FDR shows the follow:
  - The CVR transcript does not support that the RFO use his seniority to insist that he be allowed to fly the airplane, as the EgyptAir did not have a formal policy regarding crewmember relief. A relief crewmember could ask to fly at any time during a flight. In this instance, Gamil El Batouty discussed the fact that he could not sleep and offered to fly earlier than his scheduled rotation. The flying First Officer agreed with the Captain permission.
  - The CVR report raises the distinct possibility that he first officer was not alone in the cockpit at the onset of the dive. Four voices were identified on the CVR before the dive began and before the captain left the cockpit. Indeed, after the captain left the cockpit, the cockpit door was not closed, and other crewmembers were probably present or in close proximity to the cockpit. The Group Chairman’s Factual Report Sound Spectrum Study Cockpit Voice Recorder states that: “It can be concluded that as a minimum Capt. Habashy and First Office Batouty were in the cockpit during the final minutes of the recording.” Also, “it should be noted that there are several statements during the last several minutes of the CVR recording that could not be positively associated with either Capt. Habashy or 1st Officer Batouty.”

- The captain returned to the cockpit almost immediately after the dive started, at altitude of approximately 31,000 feet. There is no indication on the CVR of a struggle or disagreement between the RFO, the Captain or anyone else. There was also no effort to incapacitate the RFO or to restrain him.

- The cockpit conversations showed an effort at teamwork rather than a crew working at cross-purposes.

- Only less than 6 degrees of elevator movement occurred during the dive, even though 15 degrees of elevator authority was available at the beginning of the dive. Further, it was calculated that at the beginning of the dive the RFO's control column moved 3.5 degrees when about 11 degrees of movement was available.

- The thrust levers were reduced during the early stages of the dive. Such a control input is consistent with the RFO trying to control the speed of the airplane.

- The flight crew maintained an essentially wings-level attitude and a consistent heading during the dive. The flight crew also corrected for bank angle when the airplane began to roll. This controlled flight profile is not consistent with more radical maneuvers that would likely be used if the airplane dive was intentional.

- The FDR and CVR correlation shows that soon after the dive started, the Captain asked, "What is happening?" He asked this question three times as the airplane was recovering. If the RFO were intentionally diving the airplane, the Captain would not have asked this question as the airplane was recovering from an 18,000 feet dive.

- Commands, made subsequent to the "what is happening" questions also addressed the crew's attempts to control the airplane and did not question the RFP's behavior.

- The crew's shutting off the fuel control levers may have been a response to a potential engine flameout. The FDR recorded a warning after a low oil pressure condition. If the crew concluded a dual engine flame-out had occurred as a result of this condition and as a result of the attitude of the airplane, they would have initiated the relight procedure which starts with moving both fuel levers to the off position. A command was given a short time later by the Captain to "shut the engines." This order was confirmed by the statement, "It's shut." This shows a crew working together.

- Radar returns show that the flight crew recovered the airplane from the dive. This also indicates that the crew was working together to control the airplane.

- Simulations at Boeing suggest that the Captain and the RFO were not alone in the cockpit during the dive. The presence of others is indicated by the fact that if either the Captain or RFO had let go of their control columns to shut the engines or to deploy the speedbrake (as shown on the FDR), the airplane would have pitched down at the same time. No such change in pitch was recorded on the FDR.

- At the same moment the elevators split, the inboard and outboard ailerons showed behavior that was not consistent with the way they should behave with respect to the Boeing 767 aileron system design. Further, when this unusual aileron movement occurred during the dive, the airplane's speed was approaching Mach 1.0, and no published performance data is available to predict what will occur to the ailerons at these high speeds. It is likely, however, that aerodynamic shocks or flutter were occurring at the control surfaces, and this may have caused the uncommanded, unusual aileron movement. Knowing why the ailerons moved so unusually at the same time as the elevator spit may provide an accurate explanation for the unusual elevator movement.

- It is clear from the FDR that the autopilot was disengaged several seconds before the dive began. There is however, no direct evidence from either the CVR or the FDR to explain why the autopilot was disengaged. There is some evidence to indicate that the RFO may have been addressing an operational concern, such as:

    a. In Capt. Gamal Arram's[12] post accident interview, he indicated that he noticed unusual control column movement which caused him to disengage the autopilot, trim the airplane, and attempt to re-engage the autopilot again three times. This could be why the RFO disengaged the autopilot at 01:49:45.

    b. Analysis of available radar information indicates the possibility of at least three high-speed objects in the vicinity of the airplane and along its flight path just before the dive. If present, the RFO could have perceived these unknown objects as conflicting traffic.

2.2.3 Psychiatric Analysis

The best evidence of RFO's state of mind is the expert prepared by Dr. / Adel Fouad. His report, in its entirety, is set forth below:

Psychiatric Report Re:

Captain Gamil El Batouty - EgyptAir Accident Flight 990Work records either in the Air force or Egypt Air are satisfactory. No complaints from his colleagues or

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[12] Capt. in-command for the accident airplanes flight from JFK to LAX in the day before the accident.

bosses. No history of psychiatric referral or treatment. No history of intractable medical illness. His last general medicals check up at the aviation medical council was satisfactory (on 28th of July 1999).

In the Air Force he worked as an instructor in Military Aviation Academy. He did not join actual combat in the war. After 1973 war he returned to EgyptAir and continued employment.

I interviewed the family after the accident. Capt. Batouty was married and had 5 children and 3 grandchildren. His sons are university students and two of them are about to be graduated. One of them is already working. The family appears, to be stable and greatly respecting the deceased father. Capt. Batouty was almost a father figure for many of his relatives. Some of them showed marked grief reaction after the accident. Interviewing the relative's points that captain Batouty had an affectionate personality with no psychopathic trends. He used to support many relatives financially as he was well off. There is no family history of mental illness nor suicidal attempts.

Captain Batouty had no previous psychiatric treatment. He did not talk about suicide to any family member and did not leave any hint or written paper concerning this. He was making preparations for the marriage of his son in two months time.

His small daughter had an illness (LE) and he took her several times to Doctor David in California. During the last visit Capt. Batouty's son Grim told me on the telephone that Capt. Batouty was bringing home a few things for the family. Among them, two tires for their car in Cairo. His wife Omayma told me that Batouty did not ask to leave the company, as he was already retiring in February. She said that he had many financial projects in his mind. He was due to take a good amount of money on his retirement from Egypt Air, almost 400,000 Egyptian pounds.

The letter from Cap. Batouty's friend Dr. Moh. El Rafei M.D. showed clearly the moral and mood before the accident. Dr. El Rafei is a leading psychiatrist practicing in U.S.A (copy of his letter included).

I interviewed his friends in EgyptAir, especially his close friend Capt. Badrawy. There was a consensus of opinion that Batouty was always cheerful and that he loved life. He always accepted any pressure with satisfaction. He did not smoke or drink. While in New York on the day before the accident, Batouty gave Capt. Badrawy a few tablets of Viagra. When Capt. Badrawy asked for more tablets, he refused and said, "I keep the whole bottle for many friends in Cairo."

I reviewed the interview summaries done by NTSB witness group, which was led by Bart Elias and others on 1 Nov. 1999. According to the interview summaries

Capt. Batouty appeared to be friendly and helpful to others. Just before the accident there were no unusual events and everything appeared normal.

I listened to the CVR on 30th November. I can divide the recording into several parts:

a. Entrance of Capt. Batouty into cockpit:

> There was a discussion about who would take over the first officer duties for the first part of the flight. This ended by Capt. Batouty saying, " I am going to eat outside then come back." However, copilot Adel asked Capt. Batouty to take over and the latter accepted and then asked for dinner.

b. A period of discussion between the-pilots:

> The discussion was mainly about criticism of other pilots and policies inside the company. This went on for some time and Capt. Batouty participated in the conversation. However, he does not sound angry rather he was calming and soothing to the others. He told Capt. Habashy not to worry, "Everything will be alright."

c. Just before the accident:

> It was evident that Capt. Batouty had just finished eating and enjoying his dinner. The hostess asked him 'Do you want more food?" He replied using the Arabic expression 'Keda Foll awy" (No thank you, it was marvelous.).

d. First stage of trouble:

> There is not much talking in this segment, other than Capt. Batouty asking repeatedly in an apprehensive way for the support of god using the word "Tawakkalt Ala Allah".

e. Final stages of trouble:

> Here there are many anxious voices. The way the voices address Capt. Batouty shows that Batouty was responding and cooperating with them.

Comment:

The CVR recording gives us a unique chance to listen and examine the affective state of the crewmembers just before and during the accident. What is important is not only the content of Capt. Batouty's speech, but also the manner and the tone of speech. A sudden change occurred from the confidence, calmness and enjoyment to that of hesitation, apprehension and perplexity. There is no internal illness that can cause such a sudden change, rather this is consistent with confronting an overwhelming and fatal external situation

The meaning of the words “Tawakkalt Ala Allah” (Arabic)

Pronounced: “ Tawakkalt Ala Allah”

Dictionary meaning: “ I rely on God “ or “ I put my trust in God”

This short sentence is very commonly used in Egypt. To know the exact meaning and uses of this sentence a western person should understand 1st the underlying Eastern religious background.

A basic Islamic belief is that during life humans are continuously supported and controlled by God. A religious person believes there are limitations to all his abilities. Consequently in any act he needs the support of God so as to be successful. The more the person is a believer the more common that he uses this sentence, so much so that many people may use it during routine minor acts like starting his way to work every morning.

Another important point about the use of this sentence, it is used only when one embarks on a good action and not a bad one. Good and bad as seen by his own society. Examples of good acts where this sentence could be used e.g.; Major one like trying to save a person from drowning e.g. minor ones like starting a journey by bus or train.

Examples of bad acts where this sentence could never be used. e.g. major acts like killing somebody or planning to rob a house. . .etc. e.g. minor acts like intending to hit his son or to quarrel with somebody.

Persons committing suicide usually take, some preparatory measures to prevent anybody from discovering their act or saving them back to their miserable life. Capt. Batouty did not take any measure of this sort, e.g. closing cockpit door.

Conclusion:

There is no psychiatric evidence that Capt. Batouty was suffering from depressive disorders or bipolar illness which contribute to 70% of suicide related deaths.

Also there is no evidence of schizophrenia, alcohol abuse or any psychotic condition.

Going through the data before and during the Flight 990 crash does not lead to any suspicion of deliberate suicide act.

Dr. M. Adel Fouad
M.R.C. Psych. London
Consultant Psychiatrist

2.2.4 E- Cab Simulation Tests (March 2000):

In addition to the inherent limitations of the E-Cab as shown in Section 1.16.1 “Simulator Tests” above, the E-Cab, as a fixed-base simulator could not duplicate the vertical load factors of between –0.1 and +2.4 experienced by the Flight 990 crew during the accident sequence. Because the crew’s ability to exert force on the flight controls would have been greatly diminished, and might even have been non-existent under zero or negative “g” circumstances, the use of the E-Cab to evaluate crew responses could be misleading in some areas. The following were noticed:

- If there are only two pilots in the cockpit, all actions shown by the FDR can be accomplished, except moving the speedbrake lever to deployed position. Pulling force at the column cannot be maintained at the same level when moving the speedbrake; consequently the pitch cannot be maintained. Speedbrake deployment is possible, however, if there is a third pilot because as shown in the FDR, pitch can be maintained.
- It is not easy to move the speedbrake from the F/O side while pushing or pulling on the column.
- When pulling from the Captain or F/O side, any attempt to move the engine levers will be accompanied by the forward movement of the column and a change in pitch.
- With 6 degree TED maintained on the right elevator, the airplane was recoverable from the left side even when recovery started after 40 degrees airplane pitch down (engines shut down, speedbrake deployed).
- More importantly, as a fixed-base simulator, the E-Cab could not duplicate the vertical load factors of between –0.1 and +2.4 experienced by the Flight 990 crew during the accident sequence. Because the crew’s ability to exert force on the flight controls would have been greatly diminished, and might even have been non-existent, under zero or negative “g” circumstances, the use of the E-Cab to evaluate crew responses was not appropriate and could be misleading.

The results of the E-Cab test strongly suggest that the actions performed in the cockpit for EgyptAir 990 (when synchronized with the CVR/FDR data) can only be accomplished by at least three persons. Therefore, it is likely that during the dive, there were at least three persons in the cockpit.

2.2.5 Speech Study Analysis

- **Pilots Cooperation**

The most direct linguistic evidence for pilots working together, was provided in the repetitive general inquiry “what’s happening?” which was repeated three times, and the statement “Gamil, what’s happening?” at 0150:06, where the speaker identified another crewmember by name. First Officer Batouty was the only crewmember with the name “Gamil.” It appears that the speaker was acquainted with First Officer Batouty, recognized him in the cockpit, and believed that Batouty could help explain what was happening. The inquiry repeated at 0150:08.5 and at 0150:15.10 with a difference of approximately nine seconds between the first and the third inquiry, with no reply from the RFO which means that both pilots had no explanation for what was going on. The statement “pull – pull with me” repeated four times at 150:31.30, 150:32.80, 150:34.80, 150:36.90 is a good indication that the Captain and the RFO were doing the same action and were cooperating to save the airplane and their lives.

- **Physical effort**

A study for physical effort exerted by the crew during the accident could not be done because physical effort cannot be sensed with the area microphone. The only way to sense the breathing sounds is through hot microphone (See NTSB Final Report for USAir flight 427 accident, page140), and the Captain and RFO did not use the boom set “hot mike” during the dive.

- **“Control it”**

The words “control it” were announced in a non Arabic Language from a human voice and from the rear of the cockpit. All conversations in the cockpit between the pilots were in Arabic except the technical words. The phrase was followed by sounds that could not be identified.

- **The phrase “Tawakkalt ala allay”**

The inter-phrase intervals and the phrase duration were correlated to

The other FDR and CVR data, which showed that:

a. The phrase was announced for first time at 148:40.40. Unidentified sounds, First Officer Seat movement and Autopilot Disengagement followed the phrase, which is logical because the phrase is normally said before starting work.

b. Eight seconds later, the phrase was repeated ten times within twenty seconds. It then stopped and was never repeated. See Figure 21[13]. It can be noticed the phrase started again as the right elevator fell down and stopped as both elevators started to move towards the neutral.

c. After the Captain entered the cockpit, the RFO repeated the phrase twice. If he had been doing something wrong, he would have stopped repeating the phrase.

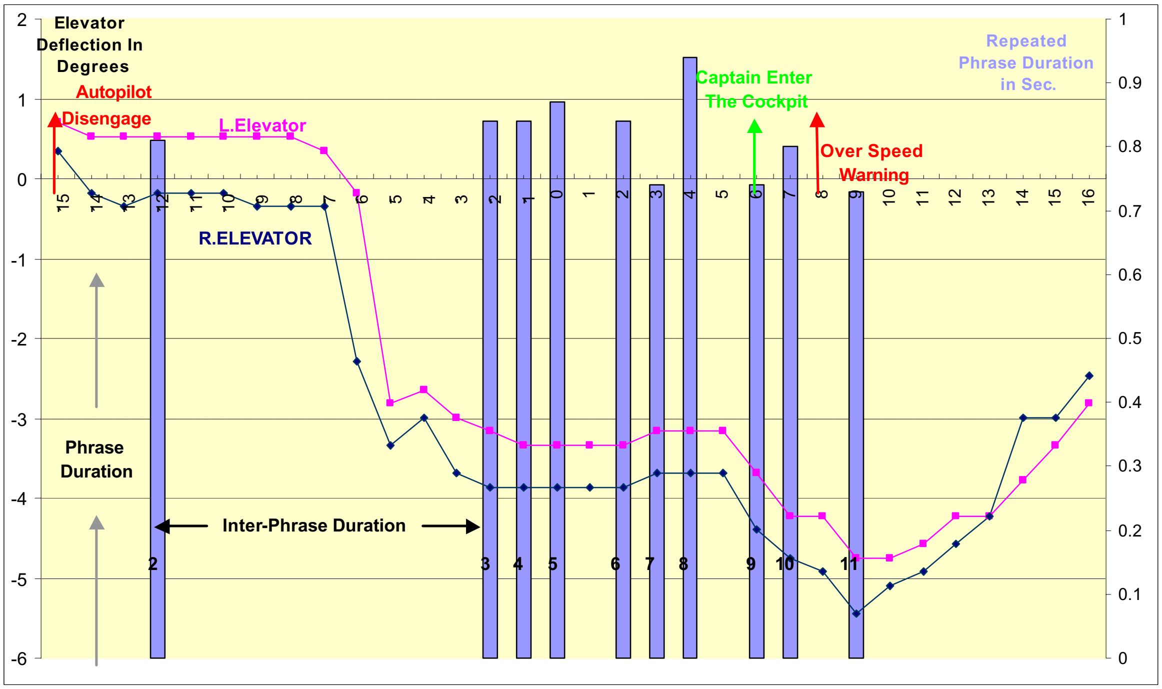

Figure 21 The Phrase “Tawakkalt Ala Allay” timed on FDR elevator data

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[13] Height of vertical bars in blue represents the duration in seconds of the phrase “Tawakkalt Ala Allah”

- **Who was in the Cockpit?**

  a. At 0145:35, there was a discussion between a Captain Habashy, First Officer Batouty and First Officer Adel.

  b. At 0145:49, First Officer Hisham entered the cockpit. The CVR transcript shows that there were four persons in the cockpit.

  c. At 0146:11, the attendant entered the cockpit and left at 0146:18.

  d. At 0146:37, a new person "CAM-?"Entered the cockpit and had a discussion with Captain Habashy, F/O Batouty and F/O Adel. While F/O Hisham was not a part of this discussion, there is no evidence that he left the cockpit.

  e. At 0147:55, F/O Batouty stated, " Look, here's the new first officer's pen. Give it to him please. God spare you." The CAM-? Replied "yeah," and the discussion ended at 0148:01.

  f. At 0148:05, the CVR transcript states, "Sound similar to cockpit door operating." This sound was checked in the sound spectrum analyses found not compatible with the door operation sound.

  g. At 0148:18.50, Captain Habashy opened the cockpit door in his way to the toilet (Ref. Sound Spectrum Factual Report) with no evidence that any of the F/O Adel, F/O Hisham or CAM-? left the cockpit.

  h. After approximately 12 seconds, the phrase "Control It" was announced from the rear of the cockpit.

2.2.6 Sound Spectrum Analysis

Examination of the Spoken Phrases at End of Recording

During the last few minutes of the CVR recording, several spoken phrases were heard. An examination of the phrases was undertaken in an attempt to determine the person who spoke the words. The sound spectrum group examined the speech from a purely fundamental frequency and voice harmonic characteristics standpoint.

What make one person sound different from another?

Basic speech starts when the vocal cords vibrate producing a primary frequency (called the fundamental frequency) as well as multiple harmonics of this frequency. As these various sounds pass up the throat past the tongue and the lips the intensities of the fundamental frequency and of the various harmonics are altered. The complex alteration of the sounds is how an individual forms all of the unique sounds needed for aural language. This unique alteration of the sound is also what makes one person's speech characteristic different from another's. (For more details, refer to the Sound Spectrum Factual Report at the docket Exhibit 12).

Who Was In the Cockpit During The Last Two Minutes of the Recording?

By examining phrases in Figure 22, it can be seen that they can be assigned into four distinct groups based on their voice print characteristics.

CVR Time EST	Similarity Group	Spectrum Time in Elapsed seconds	Generic Text of the Phrase
1:48:30.69	C	1758.41	Unintelligible phrase (Control it)
1:48:39.92	C	1767.80	F/O repeated Phrase 1
1:49:48.42	A	1836.40	F/O repeated Phrase 2
1:49:57.33	A	1845.30	F/O repeated Phrase 3
1:49:58.75	C	1846.05	F/O repeated Phrase 4
1:50:00.15	C	1847.56	F/O repeated Phrase 5
1:50:01.60	A	1849.07	F/O repeated Phrase 6
1:50:02.93	A	1850.38	F/O repeated Phrase 7
1:50:04.42	A	1851.67	F/O repeated Phrase 8
1:50:05.89	A	1853.14	F/O repeated Phrase 9
1:50:06.37	C	1853.46	Repetitive general inquiry
1:50:07.07	C	1854.53	F/O repeated Phrase 10
1:50:08.48	C	1856.18	F/O repeated Phrase 11
1:50:08.53	D	1856.26	Repetitive general inquiry
1:50:15.15	D	1862.78	Repetitive general inquiry
1:50:24.92	C	1872.18	Engine status inquiry
1:50:26.55	B	1873.80	Engine instruction 1
1:50:28.85	B	1875.84	Engine instruction/question 2
1:50:29.66	C	1876.87	Response
1:50:31.25	B	1878.45	Pull comment 1
1:50:32.75	B	1879.96	Pull comment 2
1:50:34.78	B	1882.00	Pull comment 3
1:50:36.84	B	1884.03	Pull comment 4

Figure 22 Phrases Similarities

Group A: They all have similar vocal characteristics.

Group B: They all have similar vocal characteristics

Group C: Could not be sorted into either of the previous Groups A or B. Group C does not resemble either of the previous two groups nor do they resemble each other.

Group D: Could not sorted into any of the other 3 groups but they do resemble each other.

The majority of the phrases sorted into Groups C and D contained very poor speech signal definition. This was attributed to either coincident loud background noises masking the speech signals or the words were spoken very softly.

The results shown in Figure 22 support the conclusion that there were more than two persons in the cockpit, especially at the start of the dive where repetitive general inquiry phrase was announced and at the time of the engine shut down. It should be noted that there are several statements during the last several minutes of the CVR recording that could not be positively associated with either Capt. Habashy or 1st Officer Batouty (Sound Spectrum Study Factual Report).

Cockpit Door Operation

An examination of the cockpit door operation sound in the CVR during early time in the accident flight (Figure 23) was undertaken with comparison with a reference door open sound, and the result was compared with all recorded sounds in the last few minutes of the CVR. This produced the following conclusions:

- The recorded sound[14] at 0148:05, was found not similar to door operation sound.
- Captain Habashy opened the cockpit door at 0148:18.5 on his way to the toilet, and the door remained open until the end of the FDR recording.

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[14] This sound was recognized by CVR Group as a door operation sound

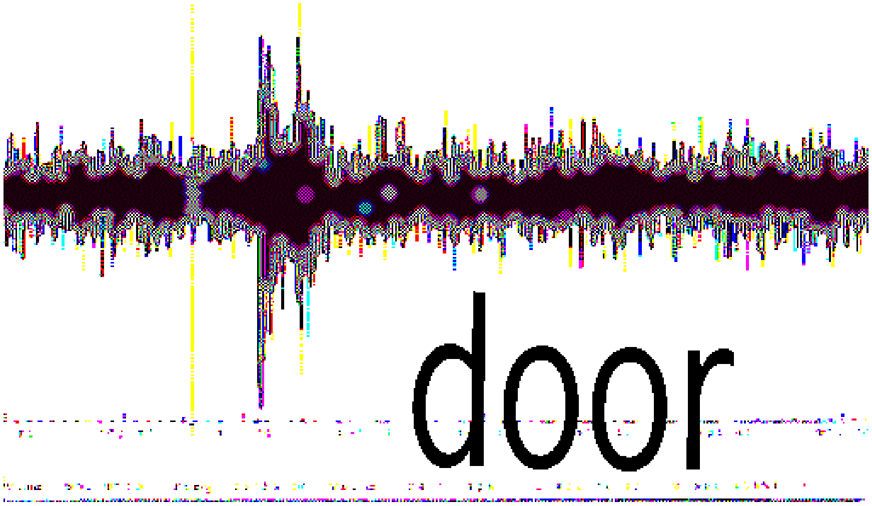

Figure 23 Cockpit door operation examination.

Examination of the phrase “Control it”

Human speech that sounded like the words “control it” was recorded by the CAM on the CVR at 0148:30.69. This was examined to document the characteristics of the comment. It can be seen from the spectrum plot shown on Figure 24 that the phrase appears to contain human speech characteristics

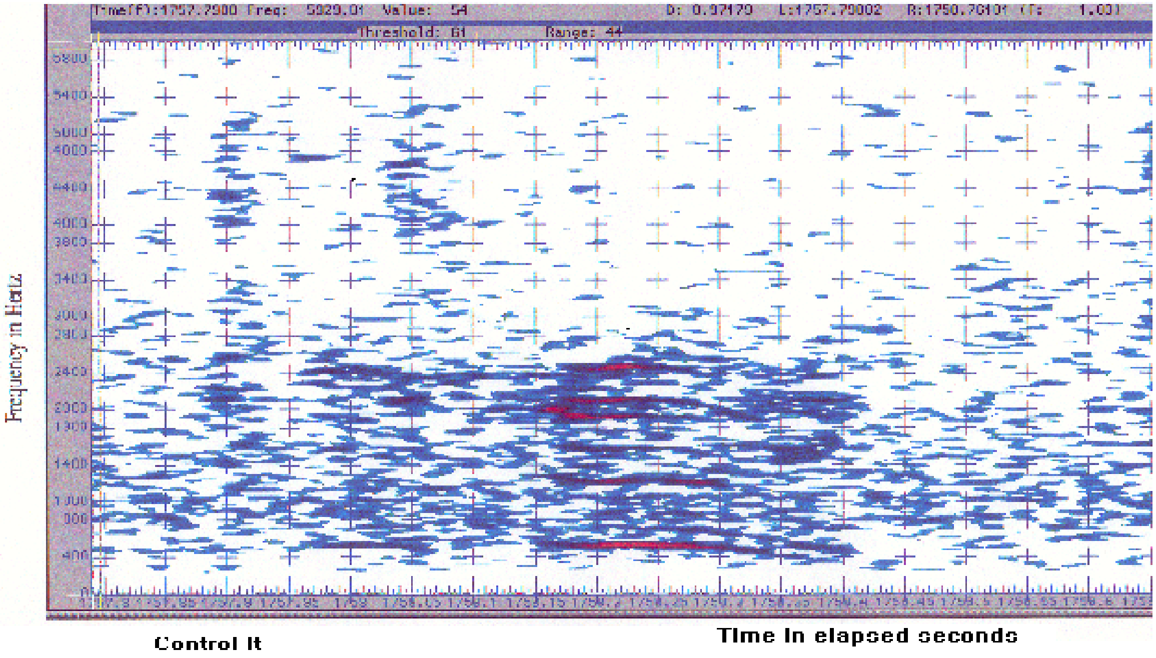

Figure 24 Phrase “Control It” Sound spectrum

Unfortunately the speech segment was not of sufficient length or clarity to positively determine who said it. The phrase was announced from the rear of the cockpit and was recorded the area microphone only, while both the area microphone and the First officer hot microphone recorded the following:

- Food Tray Sounds[15] seven seconds previous to the phrase.
- Unidentified sounds (may be panel switches) four seconds after the phrase.

The comment "Control it" had a fundamental frequency of 163.0 Hz. The comment print out was compared with the sounds of the pilots who entered the cockpit, and there was no match. Comparing First Officer Adel's sound[16] print (Figure 25) with First Officer Aiad's sound[17] print (Figure 26) is a good example for how much the fundamental frequency of two persons can be approximately the same and the voice completely different.

From the above mentioned, it becomes of prime importance to observe that this phrase that took place 75 seconds before the autopilot disconnection is the initiation of the whole event and therefore must undergo an in-depth process of analysis. Any conclusion should consider the above mentioned matching criteria.

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[15] In this time the RFO was having his meal.

[16] First Officer Adel sound fundamental frequency is 194.8 Hz.

[17] First Officer Aiad sound fundamental frequency is 193.0 Hz.

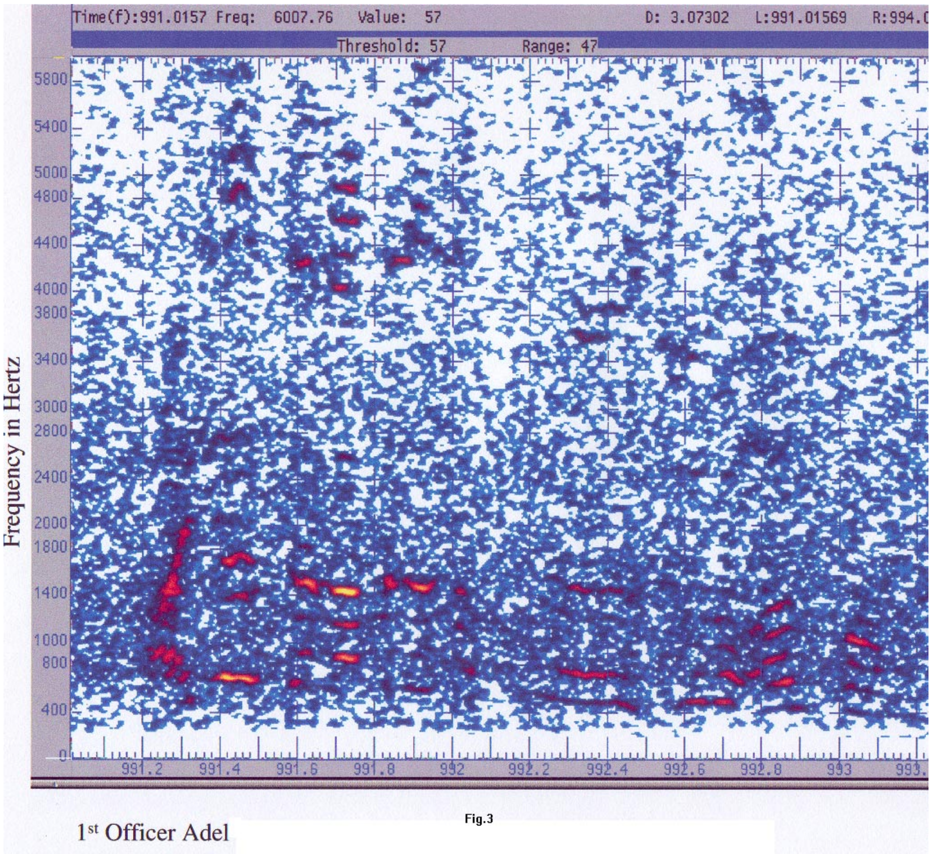

Figure 25 First Officer Adel frequency spectrum

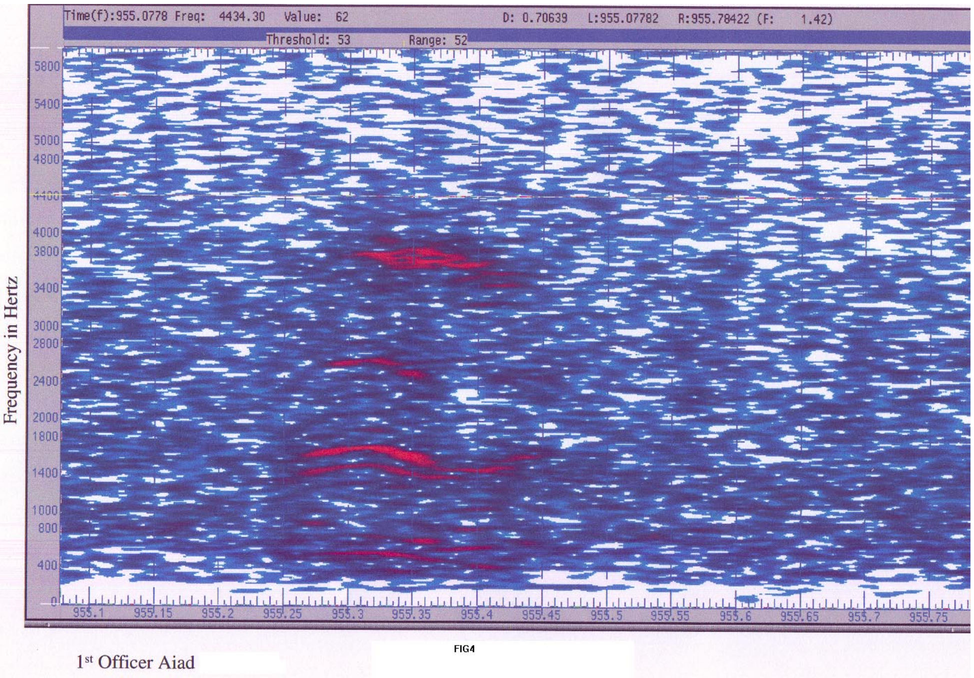

Figure 26 Figure 23 First Officer Aiad frequency spectrum

2.3 Analysis of Possible Mechanical Failures:

2.3.1 Overview

Because this accident involved a pitchover, the behavior of the elevator control system is critical to the understanding of the cause of the accident. In the elevator control system, as with any engineering system, there are correlations between various parameters within the system. For some engineering applications, there is a very strong correlation such as between the distance that a simple object falls and the time it takes to travel that distance. In other engineering applications, however, the relationship between parameters is less precise. For example, if an oddly shaped object is dropped, the time it takes to fall a given distance will vary depending on the orientation of the object as it falls, the density of the air, movement of the air mass, and many other factors. Under such circumstances, the time it takes to fall will always be in a certain range, but it is not good engineering practice to state that there is a one-to-one relationship between height and time for the falling of an oddly shaped object. These comments also apply to the analysis of the Boeing 767 elevator control system.

In the elevator control system, there are relationships between column force and elevator position, column force and override disconnection, and many other combinations of factors. Some relationships are very well understood and are not significantly influenced by second-order factors. An example of a strong correlation is the effect of body angle on elevator blowdown position. Most other relationships are not as one-to-one. An example of a relationship that is not as strong is the one between column force and elevator position. There is a range of elevator positions for each column force, the precise value depending on the direction of elevator movement, the unique frictional characteristics of the elevator control system in that particular airplane, the sensitivity and accuracy of the measurement devices, the rate at which the force is applied, the flight conditions, the imposed column feel pressure, the load factor imposed on the airplane, and many other factors. A unique elevator position cannot be assigned to a particular column force. The appropriate engineering approach is to recognize that there is a range of possible elevator positions for a give column force.

In this portion of the report, along with an analysis of the behavior of the elevator control system on EgyptAir 990, several examples of a failure to recognize the above engineering principles will be presented. This will be accomplished by discussing the analysis as follows:

- The discussion will begin in Section 2.3.2 with an analysis of the possible elevator PCA failure modes. The analysis used all available data for the elevators on the Boeing 767, which extended up to but not beyond a Mach number of 0.91. The analysis shows that a dual servo failure is consistent with all of the available recorded information.
- Section 2.3.3.1 contains an analysis of performance. This analysis used the recorded radar and the FDR data.
- In Section 2.3.3.2, there is an analysis of the FDR elevator positions during the dive of EgyptAir 990, during the 25 hours prior to the accident for EgyptAir 990, and during the flight of an exemplar Boeing 767. This analysis shows that when the autopilot was disconnected, the behavior of the elevator on EgyptAir 990 throughout the 25 hours of recorded data was consistent with a pre-existing right elevator PCA failure and no such indication was found on the sister Boeing 767.
- In Section 2.3.3.3, the unusual behavior of the elevators during the split is discussed. The movement of the elevators is correlated to the unusual behavior of the ailerons that occurred at the same time. The only explanation for the uncommanded aileron movements is transonic aerodynamic effects; therefore, the same explanation could apply to the unusual movements of the elevator.
- In Section 2.3.3.4, it is shown that the rolling moment that would have resulted from the recorded split elevator is greater than could have been controlled by the recorded aileron deflections, thereby suggesting that the

recorded elevator split did not actually occur. It is also shown that the recorded pitch angles are consistent with some or the entire right elevator having broken off the airplane at the beginning of the recorded elevator split.

- In Section 2.3.3.5, there is an analysis of the ground test results, which revealed that the elevator control system on the test airplane did not behave exactly as was predicted by the Boeing engineering data. Therefore, the engineering data (that did not exactly match the behavior of an actual Boeing 767) should be very carefully used when evaluating the possibility of an elevator malfunction as being a cause for the EgyptAir 990 accident. In particular, care must be taken when comparing the FDR elevator data and with the predicted results based on this data. Numerous examples of inconsistencies in the ground testing and Boeing analytical prediction are presented in this section.

- A thorough discussion of the E-Cab simulator testing in Section 2.3.3.6 shows that the behavior of the simulator was unlike the airplane in several key aspects (motion, g loading, interconnect between columns, etc.) that makes conclusions based on the simulator performance not accurate. In addition, the E-Cab is designed to behave in accordance with the Boeing engineering data that was shown to inaccurately represent the behavior of the Boeing 767 elevator control system during the ground tests.

- As discussed in Section 2.3.3.7, an analysis of the damage to the bellcranks and one of the servos showed that the observed damaged could not have occurred during impact with the water, thereby suggesting that at least some of the damage to the elevator control system had occurred before EgyptAir 990 crashed.

- In Section 2.3.3.8, the effect of the Mach trim system on the movement of the stabilizer is discussed. It is shown that any stabilizer movement could not be the result of Mach trim command.

- In Section 2.3.3.9, the dynamic behavior of the Boeing 767 elevator system is discussed and related to the EgyptAir 990 accident. A dynamic analysis of the elevator control system showed that forces sufficient to separate both the front and rear override connections is attainable, although a static analysis shows that higher forces are needed for separation.

- In Section 2.3.3.10, the metallurgical analysis of the recovered elevator control system components is discussed. Several of the components had failure patterns that were inconsistent with impact damage; suggesting that at least some of the damage must have occurred before EgyptAir 990 crashed.

- In Section 2.3.3.11, the events that occurred during the dive are analyzed. With the understanding gained by the analysis discussed in the preceding sections, these events are shown to be consistent with a dual PCA failure in the right elevator.

There are several overall conclusions that that can be drawn from the analysis of the elevator control system. First, a latent pre-existing single PCA failure on the right elevator followed by a second PCA failure on the right elevator is consistent with all available recorded data related to the EgyptAir 990 accident. Second, there is evidence of possible preexisting damage in the elevator control system that is consistent with one of the PCA failures. Third, conclusions either supporting or refuting a possible mechanical failure based upon a one-to-one relationship between parameters, which does not exist, are not valid. The overriding conclusion is that, based on the recorded evidence and the known behavior of the Boeing 767 elevator control system, a malfunction of the elevator control system cannot be dismissed as a cause of the EgyptAir 990 accident.

2.3.2 Analysis of Possible PCA Failure Modes

All of the possible failure modes that were listed Section 1.6.2.2 were thoroughly studied. This study revealed that, only the elevator dual PCA valve jam failure would produce elevator behavior that would be consistent with the recorded FDR elevator data. This will be shown using the information included in the Boeing analysis for elevator Dual PCA Valves Jam Failure, Boeing letter B-H200-16968-ASI-R2, dated 29 September 2000.

- **Single PCA Valve Jam Failure -- Offset from Neutral Toward Trailing Edge Down**

According to the Boeing analytical study, this failure will induce a force of 15 pounds through the pogo of the failed PCA, pushing the control columns forward (nose down direction). The effect of this force depends on whether the autopilot is engaged or not as follows:

- If the autopilot is not engaged, both elevator surfaces would move in the TED direction. Coincident with the elevator movement, the control columns would move forward very slightly. The resultant elevator and column movements are a function of elevator feel pressure, and the elevator feel pressure is function of the speed and stabilizer position. For example, at 700 psi elevator feel pressure, the columns move about 0.9 degrees forward.
- If the autopilot is engaged, the control columns and elevator surfaces will not move, as the autopilot is capable of overcoming the induced force. Thus, this failure will be latent. This failure will produce no visible or audible warning in the cockpit.
- Upon autopilot disengagement with a PCA failure present, both elevator surfaces would move in the TED direction as described above with the case of autopilot not engaged.[18]

- **Dual PCA Valve Jam Failure (Offset from Neutral Toward the Trailing Edge Down**

According to a Boeing analytical study[19] this failure will induce a force of 30 pounds through the pogos of the failed PCA's, pushing the control columns forward (nose down direction).

Right Elevator:[20]

The two failed PCA's will be fighting against the non-failed PCA. Normal system pressure is 3000 psi, system return pressure is 50 psi, and there is a 60 psi pressure differential at the PCA compensator. This results in 2890 psi acting in the TED direction on two PCA's. The pressure in the non-failed PCA is relief pressure, 3600 psi.

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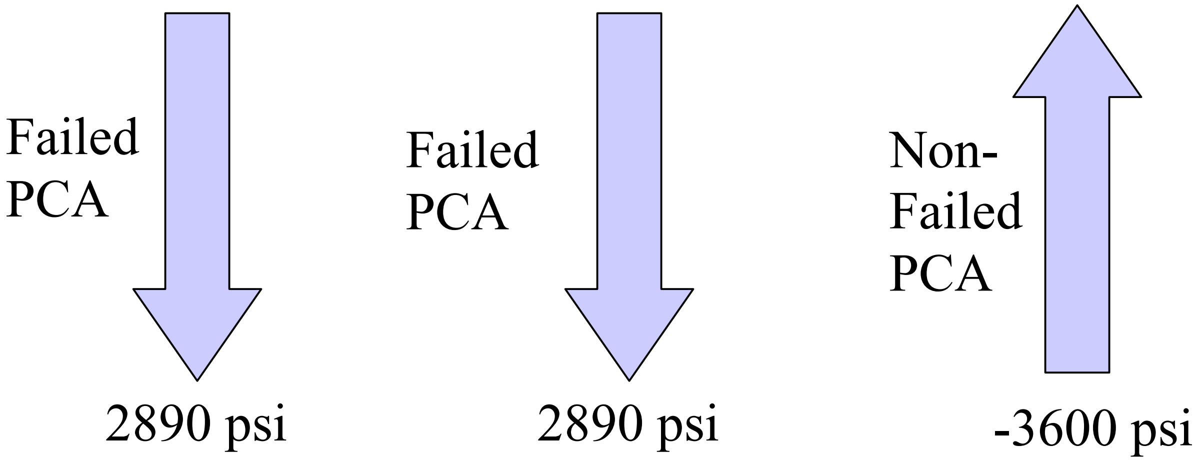
[18] Reference: Boeing letter B-H200-16968-ASI-R2 dated 29 September 2000.

[19] Boeing letter B-H200-16968-ASI-R2, dated 29 September 2000.

[20] Letter B-H200-17236-ASI "Test and Simulation Report", was issued by Boeing on 03 May 2001, containing information regarding the lab and simulator tests conducted at Boeing, Seattle on March 2001. Boeing predicted another schedule for the right elevator as a result of the dual PCA valve jam failure on the right elevator surface. Refer to Section 2.3.3.6 "Analysis of the E-Cab simulator" and Appendix A-7



The effective force acting on the elevator is:

(2890 psi + 2890 psi - 3600 psi) * PCA area = 2180 psi * PCA area

(2180 psi * PCA area) / (2890 psi per PCA * PCA area) = about 0.76 PCA

The predicted elevator behavior is as follows:

- The elevator would move to the hardover position corresponding to an equivalent of 0.76 PCA at the specific flight condition. The time required to get to the hardover position would depend on the precise positions of the failed PCA valves.
- Once the elevator is in the hardover position, the elevator will not be controllable from the cockpit.
- Once the elevator is in the hardover position, the elevator will only move under the effect of speed variation. With a speed increase, the elevator will move trailing edge up.

Figure 27 shows the recorded FDR elevator positions compared with the positions calculated using several techniques, all of which were based on Boeing documents. Line 1 in this figure shows the resulting elevator deflection from the elevator blowdown chart for an equivalent of 0.76 PCA for the appropriate flight condition.[21] Lines 2 and 3 show the resulting elevator displacement using elevator moment calculation based on hinge moment coefficients at appropriate stabilizer position, elevator deflection, and Mach number. Line 2 is the result when the body angle of attack is assumed to be constant at a

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[21] Reference: Boeing Document D613T161, Fig's 3.6-4, 3.6-5, 767-200/-300 Single Piece elevator CH curves, flaps up, stabilizer 0 and 6 units.

cruise condition, and Line 3 is the same result but taking into account variations in body angle of attack.[22]

The blowdown Line 1 is plotted only up to a Mach number of 0.91. The reason for this is that all of the data presented by Boeing is only valid up to that Mach number. It has been reported that there is no data available for elevator behavior on the Boeing 767 for the speeds above a Mach number greater than 0.91; however, the airplane's speed reached a Mach number of approximately 0.99 near the end of the dive. The blowdown Lines 2 and 3 are plotted using the hinge moment coefficients available in the provided Boeing 767 data up to a Mach number of 0.91. All calculations cease above a Mach number of 0.91 because there are no validated data beyond this speed. Of the three approaches to determining blowdown positions of the elevator, the method used to generate Line 3 is the most accurate as it takes into account variations in body angle of attack.

For comparison, refer to Figure 28, which was prepared by the NTSB Performance Group Chairman. It shows very close agreement with Figure 27.

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[22] Reference: Boeing Document D613T161, Fig 3.6-8 Single Piece elevator Blowdown curves, flaps up, one hydraulic system operating.

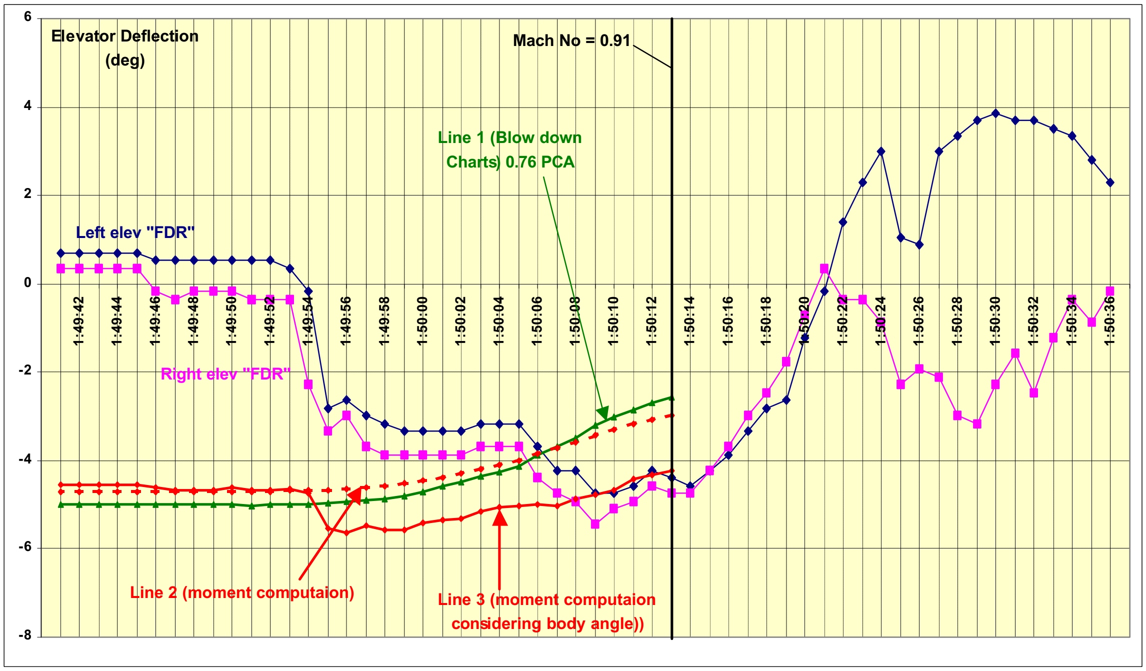

Figure 27 Right elevator blowdown with dual PCA valve jam failure

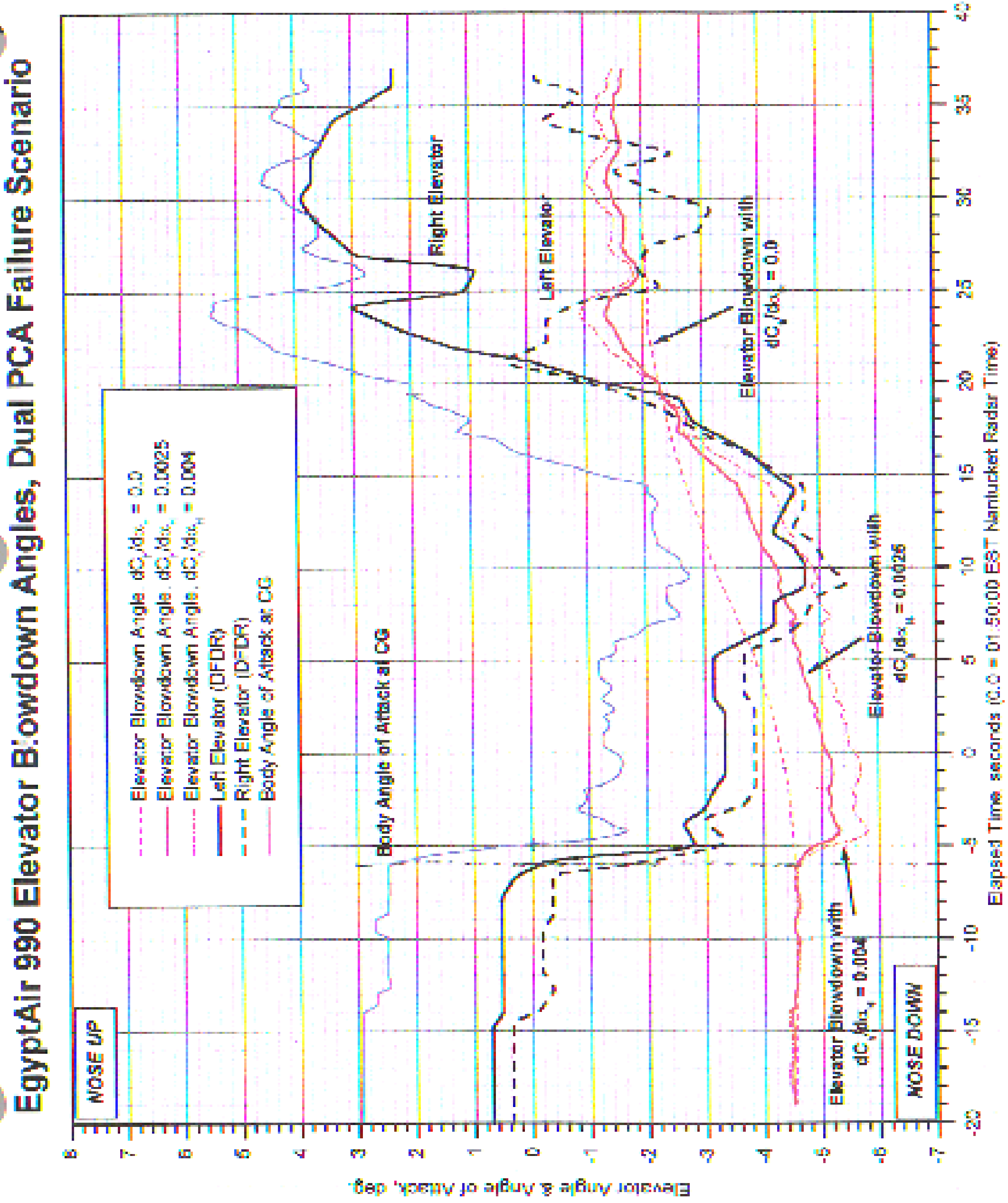

Figure 28. EgyptAir 990 Elevator Blowdown Angles, Dual PCA Failure Scenario (NTSB)

Left Elevator

With the autopilot disconnected, the predicted left elevator behavior is as follows:

- The elevator will move to the position corresponding to a force of 30 pounds applied on the control column at the relevant elevator feel pressure. The feel pressure will change with change in speed, and the elevator position will change accordingly.
- The forces required to control the left elevator surface will be much higher than the forces required in normal situations as demonstrated in the results of the ground tests.
- Commanding the left elevator from the First Officer side will be different than from the Captain's side. When applying higher forces on the First Officer column, the forward column mechanical override would break, splitting the two elevator columns. Then, with a further increase in the applied force, the aft quadrant override mechanism would break, inhibiting further command inputs to the left elevator.
- With sufficiently higher speeds both elevators would move together.

Figure 29 shows the left elevator deflection as recorded by the FDR and the resulting left elevator deflection due to the 30 pound induced force at the given flight condition.[23]

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[23] Reference: Boeing letter B-H200-16968-ASI-R2 dated 29 September 2000 Fig's 3.1, 3.2, 3.3, 3.4, 3.5, 3.6 and 3.7.

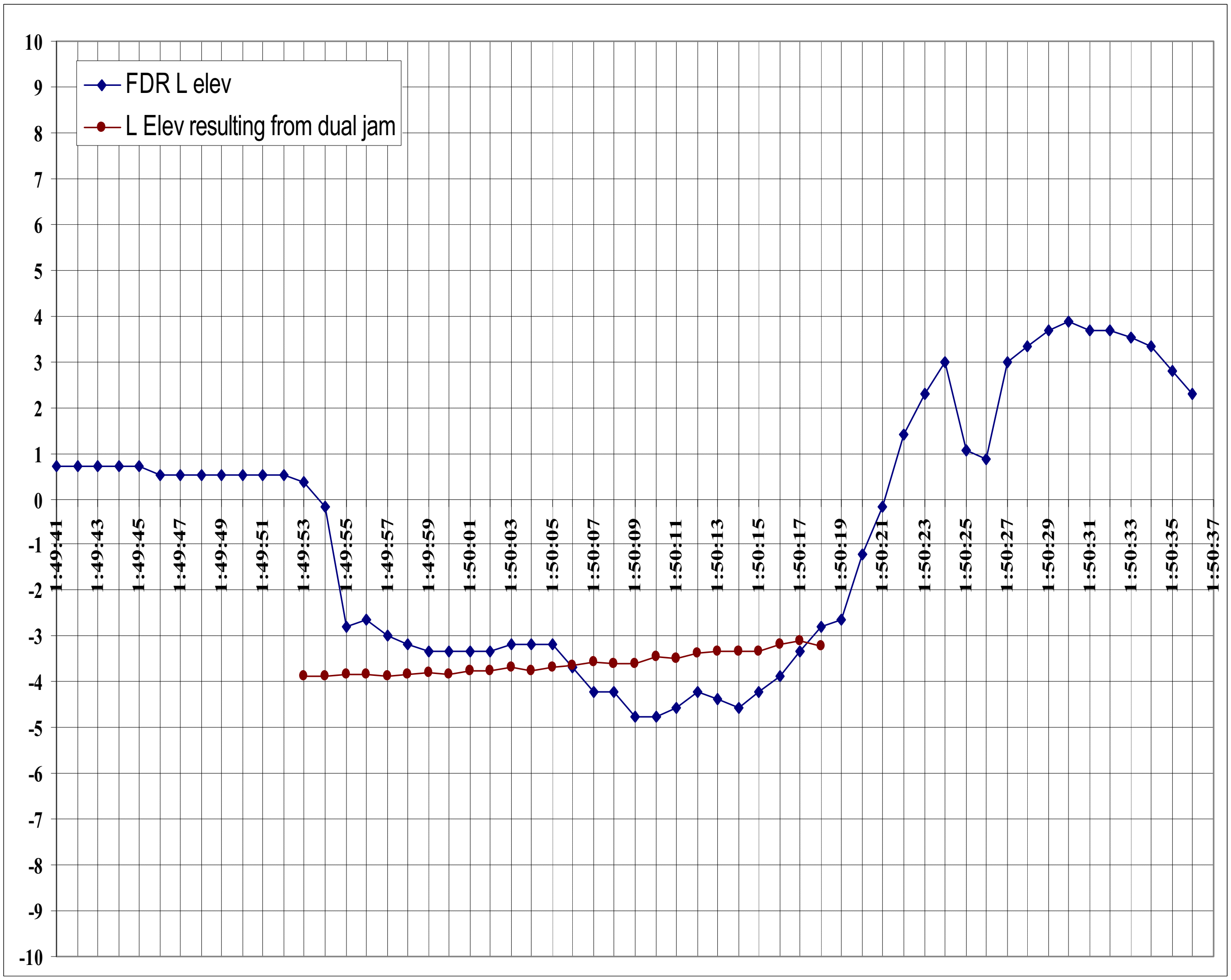

Fig 29 Left elevator deflection with dual PCA valve jam on right side

- **Dual PCA Valve Jam Failure as Applied to EgyptAir 990**

When the autopilot was disconnected, both elevators moved in the Trailing Edge Down (TED) direction, with the right elevator slightly leading the left elevator. This is consistent with a single PCA valve jam failure on one of the right elevator PCA's.[24]

The right elevator moved to the blowdown position approximately 14 seconds after the beginning of the TED movement of the elevator surfaces and remained within 0.3 degrees of the blowdown position until reaching Mach number of 0.91, showing almost an exact match with the FDR elevator data. That blowdown position was calculated using elevator moments based on hinge moment coefficients at appropriate stabilizer position, elevator deflection, Mach number, and body angle of attack (Line 3 on Figure 27). The movement of the elevator before reaching the blowdown position is dependent on the rate of flow ported to the PCA, which depends on the position of the PCA valve relative to the neutral position. Because this offset value cannot be predicted, the rate of elevator movement at the beginning of the dive cannot be used as a criterion for the match evaluation with the FDR data.

The left elevator moved to a position consistent with what is predicted based on Boeing analytical study within less than one degree throughout most of the dive.

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[24] In the Boeing letter B-H200-17114-ASI, Boeing explained the behavior of the elevator surfaces with a single PCA valve jam failure and predicted an offset in the elevator movements with the failed surface leading. The tracking difference between the two elevator surfaces was explained to be the result of elevator structural compliance, which occurs as a result of the loads introduced by a failed PCA. (Compliance in the elevator system can occur as a result of cable stretch, yield, or elastic deformation in linkages that does not damage the linkages but allows additional motion, and variations in tolerance buildups throughout the system.) This factor is ignored in Boeing letter B-H200-16968-ASI-R2 dated 29 September 2000 on which some Boeing conclusions are based. The ground tests conducted in April 2000 validated the occurrence of elevator offset; however, the offset values must be limited to the specific conditions of that test (specific single elevator feel pressure, zero air loads on the elevator surfaces, load factor of one, middle PCA selected as the failed one, etc.).

At about 1:50:09 EST both elevators started upward movement together as the result of increasing speed, which is consistent with the failure prediction. Elevator surfaces offset was less than about 0.5 degrees, which is believed to be within the elevator limitations.[25]

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[25] The elevator deflection as recorded by the FDR was examined throughout the flight. In most cases, the left and right elevators showed positions that were not identical. This offset varied in magnitude and direction throughout the flight, especially when the elevators were commanded to move away from the neutral position. The offset reached a maximum value of 1.06 degrees in one direction (L elevator leading the R elevator) at 1:20:22.98 EST and a maximum value of 1.23 degree in the other direction (L elevator lagging the R elevator) at 1:20:42.98 EST; that is, a total maximum variation of 2.29 degrees.

According to Boeing, there are several factors that could affect the offset of 767 elevators. They include rigging of the elevator control system, tolerances within the system's temperature compensation rods, routing differences between the left and right elevator control cables, friction distribution within the system, the accuracy of the sensors used to measure elevator position, and the differences in FDR sampling times for the left and right elevator parameters.

The FDR resolution for elevator deflection is 0.17 degrees; that is, the elevator position readings are rounded to the nearest 0.17 degrees.

NTSB Docket Exhibit 13 - Aircraft Performance - Addendum #2 (Addendum to Group Chairman's Aircraft Performance Study by John O'Callaghan), stated: "An exact match between the simulator and recorded elevator positions would be unexpected because of uncertainties in the flight condition and mathematical models, and because the recorded elevator positions are not necessarily the exact elevator positions experienced in flight. The elevator position signal is filtered before being recorded, so that signals from quick, abrupt movements in the surfaces may not be apparent in the recorded data."

2.3.3 other studies supporting the analysis of mechanical failure

In any accident investigation, theories as to the cause of the accident are proposed and analyzed. In the analyses, many theories are dismissed. Those that remain after all of the analysis has been competed are the only ones that are consistent with all of the available information, but there often are multiple theories remaining. The true cause of the accident is one of these remaining theories. In this section, analyses that are necessary for a complete understanding of the accident are discussed. Some of these analyses provide supporting information used in other analyses while others stand alone to support or refute potential causes for the accident. The result of these supporting analyses is that all of the available information on the crash of EgyptAir 990 is consistent with a mechanical failure in the elevator control system of the airplane.

2.3.3.1 Performance Analysis

Using standard flight path reconstruction techniques,[26] the performance of EgyptAir 990 was reconstructed based on recorded radar data. The results of the flight path reconstruction showed the maximum Mach number reached was approximately 0.99, which occurred at an altitude of approximately 26,000 feet MSL. The maximum load factor was approximately 3.4, which occurred shortly after the FDR stopped recording data. This analysis also showed that the angle of attack increased to a very high number at the top of the climb, which suggests that the airplane stalled at this time. This is confirmed by the calculated calibrated airspeed of under 100 knots at that time, which is well below the level flight stall speed.

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[26] As developed by Bach and Wingrove.

A complete report on the   Performance Analysis is contained in Appendix A-1. The results of this analysis are used throughout the rest of the analysis sections of this report, including the analysis to determine the point at which the left engine departed the airplane.

2.3.3.2 Analysis of FDR Elevator Data with Autopilot Disconnect

Although the most heavily scrutinized FDR data is for the last 60 seconds of the flight of EgyptAir 990, the FDR contains 25 hours of data detailing the airplane's performance prior to the accident. In particular, this data shows the pattern of 11 autopilot disconnects and indicates unusual patterns for several disconnects. These autopilot disconnects shed light on the unique behavior of Egypt Air 990.

During the flight a day earlier from New York to Los Angeles, Captain Gamal Arram, who was in charge of that flight, disconnected the autopilot of the EgyptAir 990 airplane three times between 10,000 feet and approximately 7,000 feet as the airplane was descending for landing at the Los Angeles airport. Capt. Arram reported that he observed an unusual movement in the control column and disengaged the autopilot to determine whether there was a malfunction[27]. When he was unable to reengage the autopilot, Capt. Arram took the unusual step of hand flying the airplane for the remainder of the flight. Capt. Arram reported that the autopilot once again functioned normally after the landing and continued to operate properly when it was checked by the maintenance crew in Los Angeles.

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[27] The elevator position signal is filtered before being recorded, so that signals from quick, abrupt movements in the surfaces may not be apparent in the recorded data. Columns positions are not recorded by the FDR

The erratic behavior of the autopilot caused Egyptian investigators to review all instances of autopilot disconnection on the 25-hour FDR recording. Of special note is that, in most of the times the autopilot was disengaged, there was an obvious downward movement of elevators, with the right elevator showing a greater deflection than the left.

To analyze this data, EgyptAir test flew another 767 and performed a series of autopilot disconnects and reviewed the FDR data from those test events. This set of test autopilot disconnects was performed during cruise on a flight from Cairo to Rome. As was expected, the data recording these disconnects and presented in Figure 5 (Factual section 1.6.3.2) showed no significant movement of the elevator between autopilot and manual operation at the moment the autopilot disconnected. This is in contrast to the data for the EgyptAir 990 airplane where there was a consistent downward elevator deflection when the autopilot was disengaged (Figure 4 Factual section 1.6.3.2). This analysis shows that an anomaly existed in the EgyptAir 990 elevator system even before the A/C left New York for Cairo on October 31, 1999 -- a latent defect that could not be detected by the crew.

In light of these facts, it is plausible to believe that -- just as Capt. Arram had done a day earlier -- the RFO on EgyptAir 990 disconnected the autopilot after observing some unusual movement in the control column.[28] Once the autopilot was disconnected, the latent defect manifested itself by an obvious change in the elevator position.[29] As shown in Figure 29, the left elevator deflected TED approximately 0.2 degrees and the right elevator deflected TED approximately 0.6 degrees. These deflections were

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[28] During the backdrive of the Boeing simulator, the investigators observed an unexpected movement of the control column just prior to the autopilot disconnect.

[29] The elevator control column positions and forces are not recorded by the FDR.

accompanied by a decrease in the vertical load factor of about 0.07 “g.” At the same time, the pitch attitude began to decrease (see Figure 30, elapsed time at the x-axis is selected to be 0 at time 1:50:00 ET). The correlation of elevator movement with vertical load factor and pitch change confirms that the recorded elevator deflection did actually occur. This deflection of the elevators with the right elevator leading is what one would expect if one PCA had jammed in the TED position.[30]

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[30] In NTSB Docket Exhibit 13 - Aircraft Performance - Addendum #2 (Addendum to Group Chairman’s Aircraft Performance Study by John O’Callaghan), the following is stated: “An exact match between the simulator and recorded elevator positions would be unexpected because of uncertainties in the flight condition and mathematical models, and because the recorded elevator positions are not necessarily the exact elevator positions experienced in flight. The elevator position signal is filtered before being recorded, so that signals from quick, abrupt movements in the surfaces may not be apparent in the recorded data.”

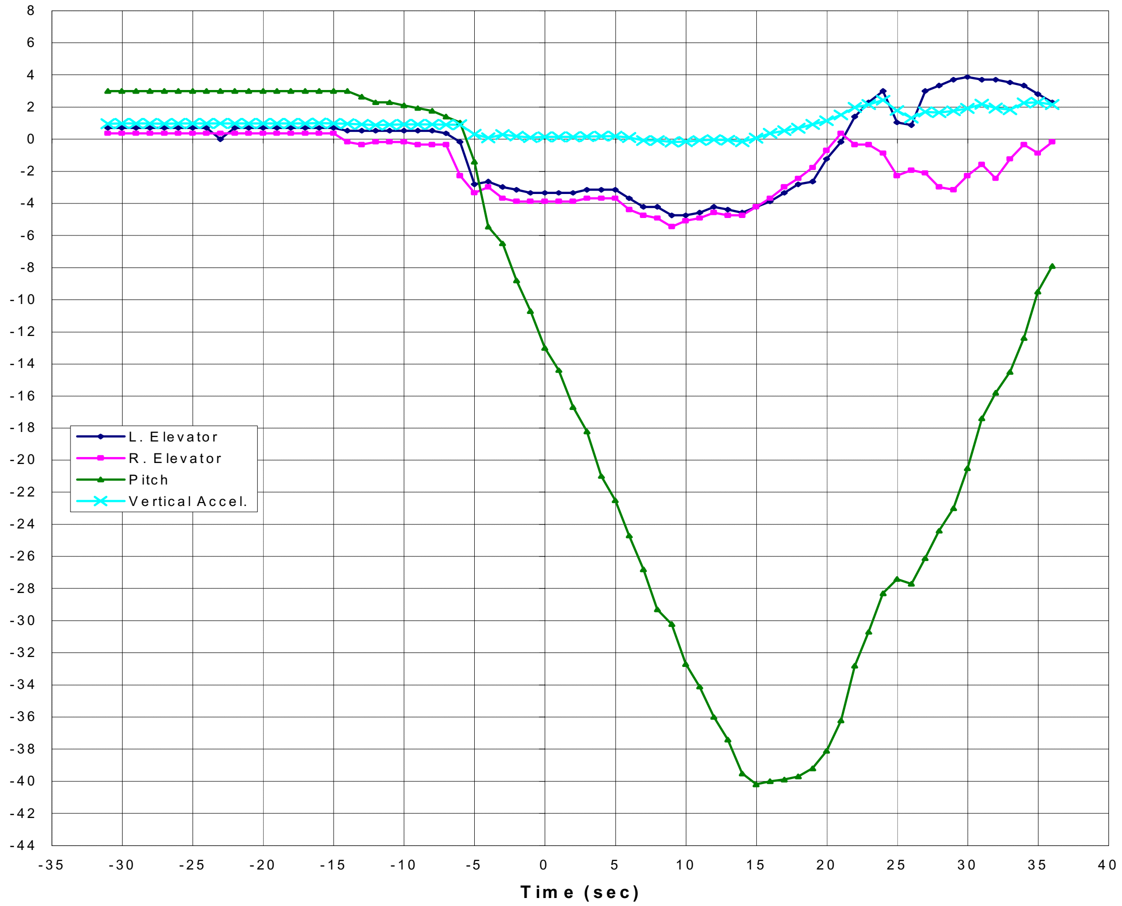

Figure 30 FDR Elevator Deflections, Pitch, and Vertical Acceleration

2.3.3.3 Investigation of Unusual Aileron and Elevator Operations

According to the FDR data, from approximately 01:50:20.98 through the end of the recording, the elevators showed a split condition with left elevator moving trailing edge up and right elevator moving trailing edge down (Fig 27). At almost the same time, the inboard and the outboard ailerons showed behavior that was not consistent with the Boeing 767 aileron system design.

Normally, the left and right inboard ailerons move in directions opposite to each other. As shown in Figure 31 prior to approximately 01:50:19, the two inboard ailerons were moving in opposite directions. However, after this time, the left inboard aileron started moving in the same direction as the right inboard elevator. At 01:50:23 EDT, the ailerons showed displacements of approximately 7 and 10 degrees in the same directions. This aileron movement cannot be commanded from the cockpit, yet it continued to the end of the FDR data.

The outboard ailerons are designed so as to be locked at higher altitudes and higher Mach numbers, as was the case just before and during the dive. However, as shown in Figure 32, both left and right outboard ailerons showed large deflections in the trailing edge up direction. Moreover, both outboard ailerons showed an offset of more than four degrees close to the end of the dive. None of these outboard aileron movements can be commanded from the cockpit.

The unusual aileron data recorded by the FDR potentially shows the ailerons moving in a manner outside the design of the flight control system and in a manner that cannot be the product of control inputs from the cockpit. Consequently, the FDR reflected either erroneous data or unexpected aerodynamic forces on the ailerons. Based on a detailed examination of the FDR data, there was no indication that the aileron data had been corrupted, accordingly, the investigation focused on aerodynamic forces.

As part of the investigation of this occurrence, the aileron hinge moments were calculated to determine whether sufficient asymmetric airloads existed to cause this condition using the same technique used to explain the elevator asymmetry (Reference: Exhibit 9 Systems Egyptian Delegation comments on System Group Chairman’s Factual Report, “Study regarding System Group activities and summary of the elevator mechanical failure,” and “Detailed study of the elevator mechanical failure (Exhibit A)” and Exhibit 13 - Performance Egyptian Delegation comments on Group Chairman's Performance Study Addendum 1).

The two possibilities that can generate asymmetric flow causing surface asymmetric movement are the roll rate and the sideslip angle. As part of the roll rate investigation, the wing angles of attack required on the left and right wing surfaces in order to overcome the hydraulic actuator and to drive the ailerons to the split positions recorded by the FDR were calculated. These calculations showed that the roll rates necessary to produce the necessary loads were between 9 and 19 times greater than the roll recorded on the FDR. Accordingly, there is no evidence that a high roll rate caused asymmetric loading.

The sideslip calculation was based upon the fact that the dihedral angle of the wing is 6 degrees, which will cause one wing to be at a different angle of attack than the other in a sideslip. The calculations showed that to change the wing angle of attack by 5 degrees required a sideslip angle of about 40 degrees. Such a sideslip angle is inconsistent with the lateral load factor, aileron angles, and rudder angles recorded in the FDR. Further, a sideslip of this magnitude at the flight condition recorded is probably beyond the aerodynamic and structural capability of the airplane. Consequently, the asymmetric movement of the ailerons was not likely caused by a sideslip.

This analysis with respect to the abnormal aileron movement suggests that other aerodynamic phenomena were acting on the ailerons. The source of such aerodynamic pressure is likely the speed, which approached .99 Mach (transonic range). It is known that shocks will form on various surfaces as the Mach number increases, but it is not known how the pressure distributions and force coefficients will change at these speeds. Just as it is invalid to extrapolate data into a region where a lifting surface is stalled, it is invalid to extrapolate data into a region where supersonic flow will exist.

It is distinctly possible that the aerodynamic phenomena that caused the abnormal behavior of the ailerons also caused the asymmetrical movement of the elevators. There is no elevator performance data for the Boeing 767 beyond .91 Mach; therefore, analysis of the elevator movement requires further study using wind tunnel models. Demonstration of the formation of shock waves on one or more lifting surfaces could explain both the unusual aileron movement and the elevator split.

More importantly, however, it is completely illogical to attribute the unusual aileron movement to aerodynamic forces and to summarily reject a similar explanation for the unusual elevator movement occurring at the same time.[31]

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[31] In Boeing letter B-H200-17216-ASI dated 12 April 2001, Aileron Behavior, The following is mentioned: "For the Mach numbers during the time period between 1.50.12 and 1.50.17.5 EST and beyond, available wind tunnel data show that the outboard aileron hinge moments are quite sensitive to angle of attack, At the Mach numbers of interest, computational fluid dynamic (CFD) analysis shows that a small sideslip angle can produce large changes in the outboard aileron hinge moments. This is a result of an aft movement of the upper surface shock on the upwind wing aileron and a forward movement of the shock on the down wing aileron. Roll rate causes a difference in the induced angle of attack at each aileron that also changes the outboard aileron hinge moments."

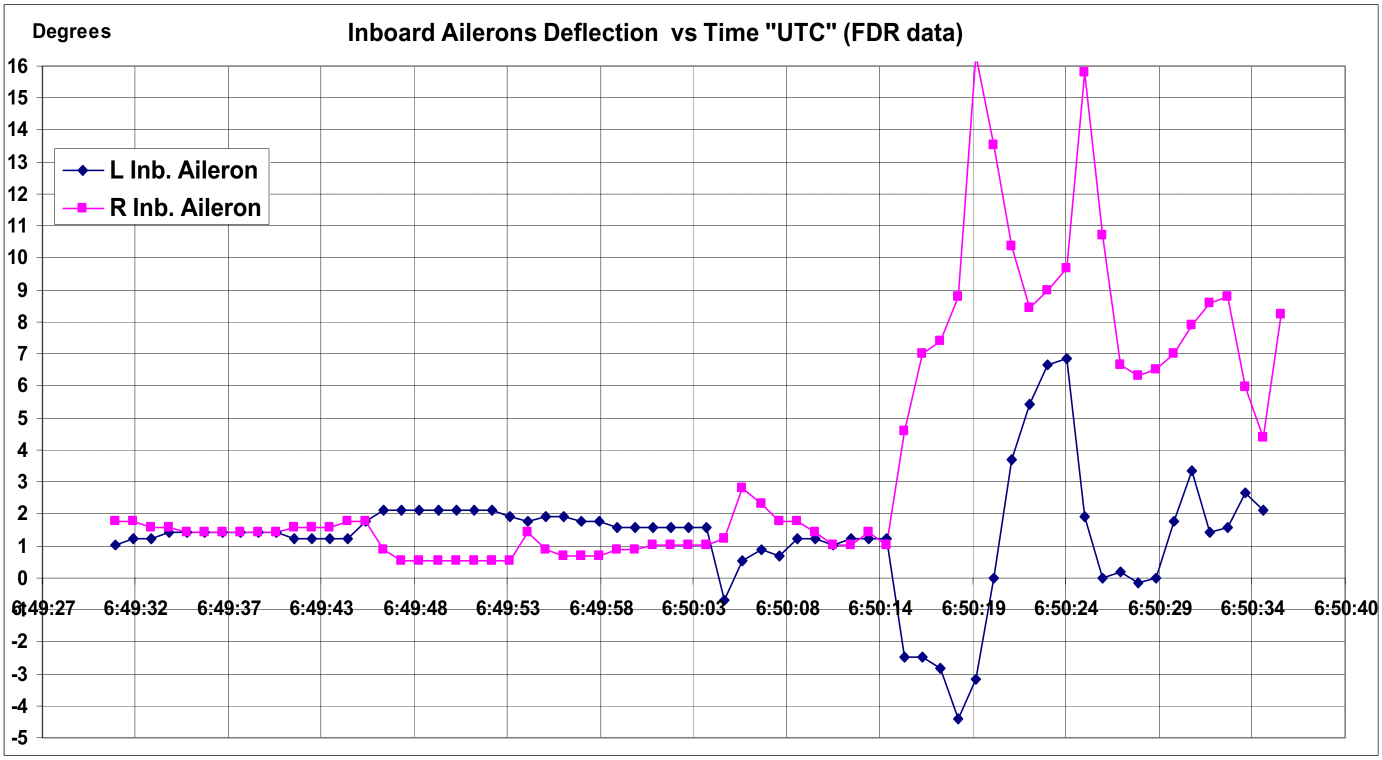

Figure 31 Inboard Ailerons deflection vs. Time “UTC” (FDR data)

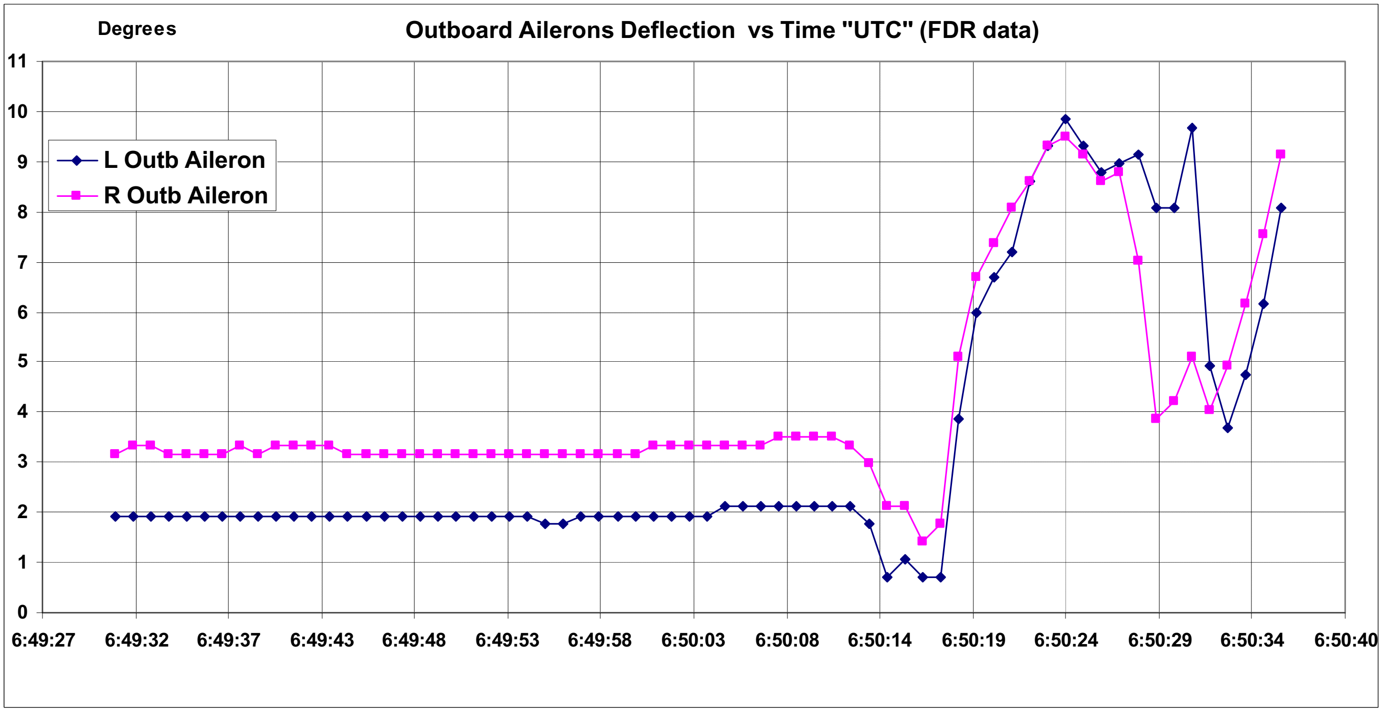

Figure 32 Outboard Ailerons deflection vs. Time “UTC” (FDR data)

2.3.3.4 Investigation into the Possibility of the Inflight Loss of the Right Elevator

In section 2.3.3.3, the possibility that the recorded elevator split was the result of transonic aerodynamic effects was explored. In this section, the possibility that the elevator split did not actually occur and that the measured values may be the result of the loss of a major portion of one or both elevators is investigated. The analysis is performed in two parts: (1) roll analysis correlated with FDR recorded elevator and aileron positions and (2) a longitudinal simulation analyzing the pitch changes during the pullout. The analysis is approximate because detailed stability derivative information on the Boeing 767 is not available; therefore, the analysis was based on the sizes and locations of the various components. Although the analysis is approximate, it shows that the rolling moment due to a differential elevator deflection is significant. It is shown in this section that the data recorded on EgyptAir 990 is consistent with some or the entire right elevator departing the airplane at about the time of the alleged elevator split. Details of this analysis are contained in Appendix A-2.

2.3.3.5 Analysis of Ground Test Data:

Because of the E-Cab limitations as documented in Section 1.16.2, Boeing conducted three ground tests sets using an actual 767-400 comparable to the EgyptAir 767.

The significant results of these sets of ground tests were:

a. The ground test results were often different from the results predicted by Boeing and the results of similar failure scenarios tested in the E-Cab.

b. With a dual PCA failure on the right elevator (dual disconnect, dual jam, or single disconnect followed by a single jam), the right elevator moved to its maximum hardover position with no response to inputs from the control columns.

c. When the PCA jam failures were introduced, the column forces needed to control the left elevator were higher than predicted.

d. The forces needed to control the left elevator were not the same for the right and left control columns.

e. Under the identical failure scenarios and elevator feel pressures, a given force applied to the control column resulted in a wide range of corresponding elevator deflections.

f. In all cases, the front override connection always separated before the aft override connection; that is, the control columns always split before the elevators split.

g. Single and dual PCA valve jam failure tests were limited to only one offset position for the jammed control valve; therefore, there was only one flow rate ported from the jammed valves.

A detailed discussion of the ground test results is contained in Appendix A-3,

2.3.3.6 Analysis of E-Cab Test Data:

Some of the limitations of the Boeing E-Cab simulators were documented in Section 1.16.1; however, there are more fundamental problems in using this tool to reach conclusions regarding the cause of an accident. In particular, the simulator was programmed to perform in accordance with the Boeing analytical study B-H200-16968-ASI-R2 dated 29 September 2000. It has been shown earlier in this report that the Boeing analytical study did not accurately describe the actual behavior of the elevator control system. The E-Cab simulations simply reproduced those erroneous results. Having two sources that repeat the same errors does not correct the errors. Consequently, it is not possible to base any definite conclusions as to the cause of this accident on the simulator results.

- **Boeing Lab and Simulator tests March 2001:**

In March 2001, the NTSB requested that Boeing develop a revised model and re-evaluate the effects of the failure in the simulator due to recently discovered errors in modeling the PCU dynamics during blowdown and blowback situations. A Bench Test and another E-Cab tests were conducted on March 2001 at Boeing Field, Seattle. The tests final report was received after about 6 weeks.

When alerted that new E-Cab testing was to be accomplished, the Egyptian Investigation Team asked the NTSB to include other effects influencing the elevator behavior with elevator failures modeling (which were ignored in the previous simulator tests). In response to these requests, the NTSB stated verbally that these effects will not be considered in the E-Cab tests but will be added to the list of simulator limitations.[32]
Boeing published another predicted elevator schedule as the result of “dual PCA valve jam failure” on the right elevator surface. Upon study of the methodology, data and assumptions used, the Egyptian Investigation Team believes that the conclusion reached by Boeing is not accurate because of (1) the acknowledged limitations of the E-Cab simulator, (2) the selective application of assumptions, and (3) the use of data that has not been accurately validated.

Refer to Appendix A-7 for more detailed study.

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[32] Relevant Boeing letter B-200-17236 ASI Dated 03 May 2001, did not contain any information regarding the Egyptian Investigation Team requests and also did not contain the NTSB statement to consider these requests as simulator limitations.

2.3.3.7 Analytical Study of the Anomalies Found in One of the Recovered Elevator PCA's:

The right outboard elevator PCA and servo were recovered. The manifold housing containing the servo valve was found attached to the PCA by the input arm. The bolts that connected the manifold housing to the PCA had been sheared. Examination of the servo revealed that the pin holding the spring guide to the slide had been sheared and the spring had looped over the spring guide.

A detailed analysis addressing the anomalies found in the PCA is contained in Appendix A-3. The acceleration needed to shear the pin is explored. The results of the analysis suggest that the PCA damage occurred before the impact with the water.

2.3.3.8 Stabilizer Control/ Mach Trim System:

The horizontal stabilizers are an important contributor to the pitch control of the airplane. In this section, the movement of stabilizers is analyzed with primary attention paid to the time just before and during the dive.

Figure 33 shows the FDR stabilizer position near the end of the FDR recording as well as the Mach number as derived from the recorded Calibrated Airspeed (CAS). The figure also shows the computed nose up stabilizer command generated by Mach Trim Speed logic, which is based on the Mach number and the position of the stabilizer at the moment of autopilot disengagement. The FDR recorded the stabilizer as moving in a narrow band about a value of 3.17 units until about 1:50:14. After that time, the stabilizer continued its movement around a value of about 3.3 units.

The Mach Trim Speed logic is disabled when the column is moved forward. A comparison of the recorded elevator position with the calculated column position at the flight condition, shows that the Mach trim command could be disabled by the elevator column cutout switches beginning at time 01:50:04. Control of the Mach trim function would then have transferred to the other Stabilizer Trim/Outboard Aileron Lockout Module (SAM) 10 seconds later at time 1:50:14.

When the transfer to the second SAM was completed, the reference Mach number would have reset to the value at that time. Since the Mach number at the time of transfer was greater than 0.88, the Mach Trim command would be reset to zero once transfer was completed. The Mach number remained at a value greater than 0.88 for the remainder of the available recorded FDR data.

The following can be concluded regarding the Mach Trim system:

- The Mach trim system would have issued a command for nose up stabilizer during the initial dive from time 1:50:00 through 1:50:13 EST.
- The stabilizer did not move in response to the Mach Trim commands from time 1:50:00 through 1:50:13 EST. The lack of stabilizer trim movement during the initial portion of the dive is consistent with nose-up stabilizer trim being disabled by the elevator column cut-out switches.
- The indicated stabilizer movements beyond 1:50:14 would not be from the Mach trim system.
- Stabilizer movement (if any) after 1:15:14 could have been the result of manual electric trim input or stabilizer standby switches input.

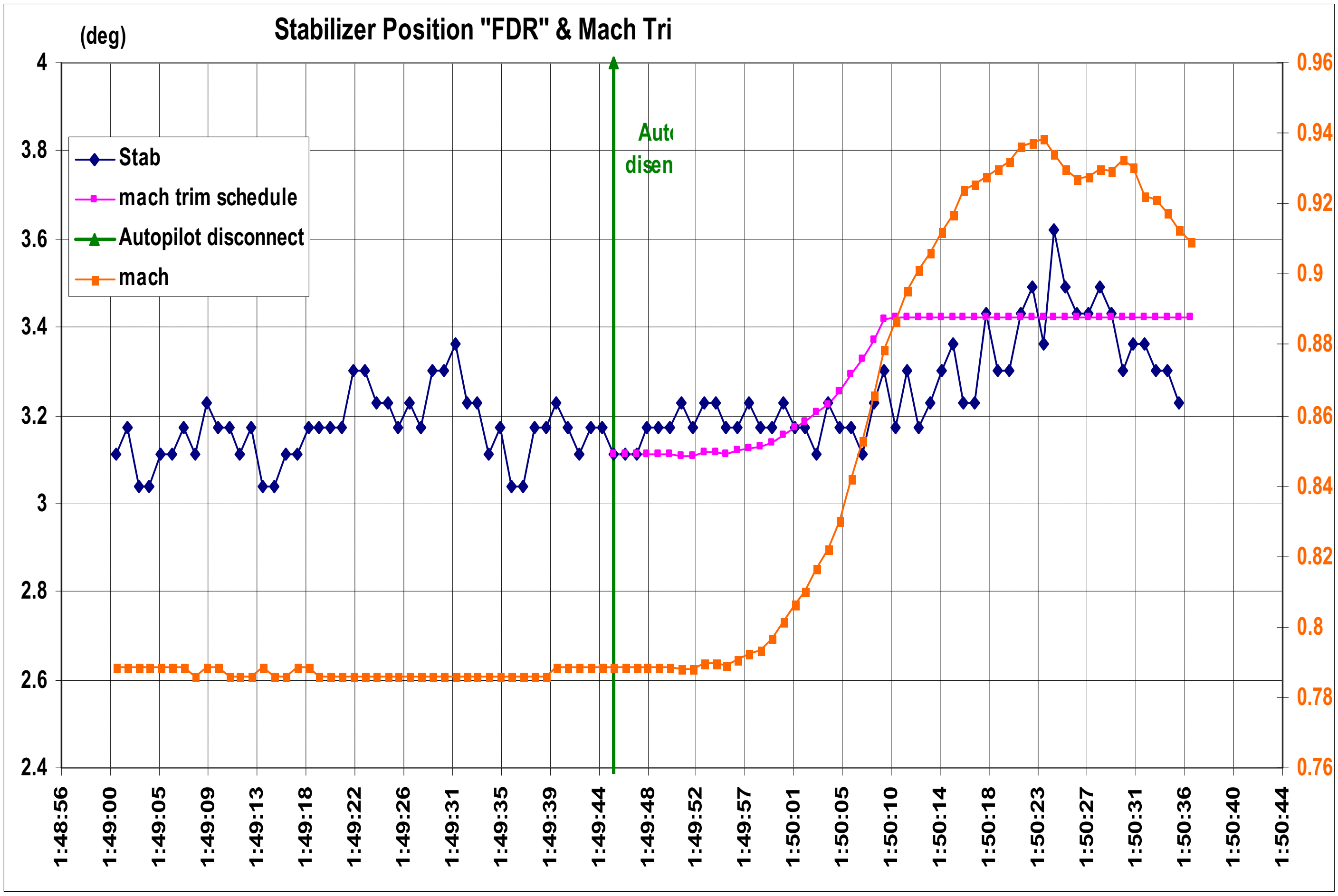

Figure 33 Stabilizer movement time history, Mach trim computed command

2.3.3.9 Dynamic Analysis of Elevator Control System

The elevator control system on the Boeing 767 has several unique characteristics. In particular, the system has the capability to completely separate the left and right sides. This capability is included to allow elevator control if one side becomes jammed. For example, if the right elevator is jammed, the pilot in the left seat can, by exerting enough force, separate the left and right sides and control the left elevator while the right elevator remains jammed. This ability to separate depends on the force applied and is discussed in detail in Appendix A-5.

This capability to separate the left and right sides of the elevator control system is implemented with the use of two override connections, one between the control columns in the cockpit and the other in the aft quadrant. These override connections transmit force as a linear spring unless the force being transmitted reaches 25 lbf. When the force reaches 25 lbf, the connection between the left and right columns separates, and no force can be transmitted. If the force applied to the aft override connection reaches 25 pounds force, the connection breaks but instead of a complete separation, the left and right sides are then connected by a much weaker spring.

A dynamic analysis of the elevator control system of the Boeing 767 based on the Boeing description of the system was performed. The analysis included the non-linear characteristics of the breakout connections. The results of the analysis showed that a force in excess of 32 lbf applied to the right control column was required to cause a separation in the front quadrant override connection. It also showed that, if a force in excess of 44 lbf was applied to the right control column, both front and rear quadrant overrides would separate. The front quadrant override separates almost immediately, but the rear quadrant override separates more than one second after the force is applied to the right column.

This analysis shows that elevator splits can occur if sufficient force is applied to one control column and the other is left unattended. This result is contrary to results of the static analysis performed by Boeing. The analysis also provides an explanation for why, with the left seat vacant, the first officer could not control the A/C.

2.3.3.10 Examination /Analysis of Recovered Elevator Component

A thorough inspection of the recovered servo valves (slides and sleeves), the bellcranks and the push-pull rod using the NTSB's Metallurgical Lab optical and scanning electron microscopes disclosed some findings that are consistent with a jamming condition in the right elevator's outboard power control actuator (PCA#3).

Following is the analysis of those findings:

1. PCA#3 is unique among the recovered PCA's with the following findings:
    a. The actuator was fully retracted (commanding the elevator to the trailing edge down, nose down).
    b. Unlike PCA #1 and PCA #2, the piston rod was not bent which indicates that the PCA might have been retracted before impact.
    c. The four bolts that attach the manifold housing to the cylinder were sheared, but the manifold was still attached to the assembly through the summing lever which revealed that it was subjected to lower impact forces than PCA#1 and PCA#2
    d. The rolled pin that attaches the spring guide to the servo slide was sheared into three pieces. The pin shear direction is consistent with the servo slide moving through the guide hole, which is not possible unless the guide was stagnant and the slide was commanded to move in the direction through the guide.

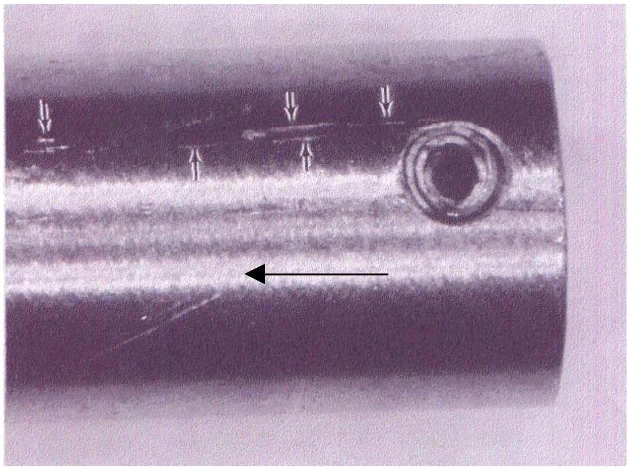

Figure 34 PCA #3 servo slide showing the pin shear direction (Black arrow) and the score marks cause by the sheared pin.

e. The bias spring was rolled over the spring guide by two rolls, as disclosed by the X-ray image, that reduced the clearance between the spring guide and the inner surface of the servo cap and increased the jamming possibility.

f. The spring guide has two narrow indentations on the outer diameter that appeared to be consistent with contact from the bias spring, which will not happen unless the spring was already rolled over the guide.

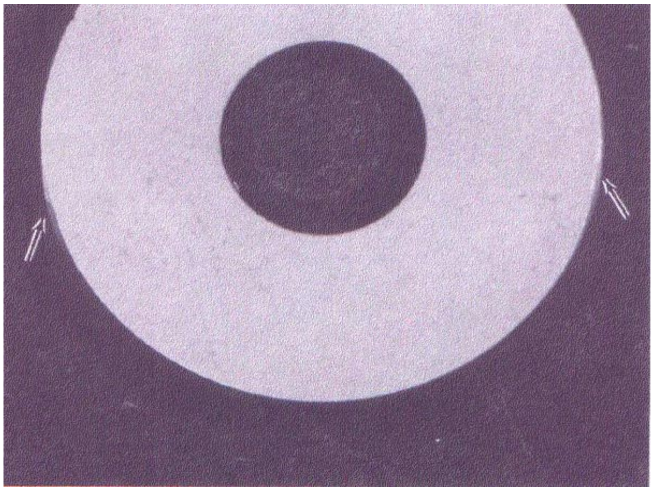

Figure 35 The spring guide with the two narrow indentations (The two indentations denoted by the two arrows)

g. One side of the guide has a rub mark adjacent to the pin hole, which might be caused by the spring trying to roll over the guide. The smaller diameter face of the guide contains a series of curved impact marks from repeated contact by the end of the servo slide, which would not happen unless the spring guide was held in position and the slide was free to impact it several times.

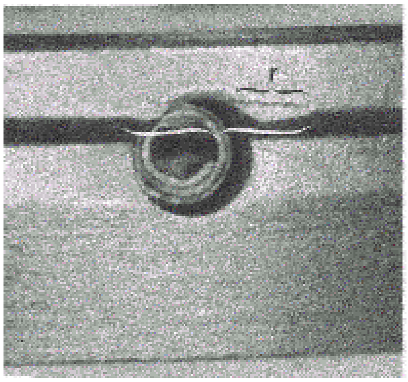

Figure 36 Showing the spring guide with the rub mark denoted by arrow “r”.

h. The servo cap contained some particles; one of them is consistent with the chemical composition of the spring guide (might be when the spring rubbed the guide), and another consistent with the chemical composition of the servo cap, which could be due to a jamming between the spring guide and the inner surface of the servo cap.

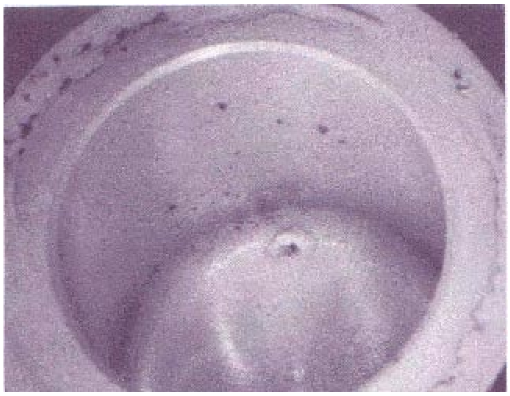

Figure 37 The servo cap with the particles shown.

i. The slide has several discontinuous score marks. Those marks suggest that the slide moved though the spring guide a maximum of about 0.28 inch, which will not happen unless the guide was stagnant and the slide was free to move. Also, the slide has a heavy wear mark on the input hole, which indicates that a high amount of force was exerted to move the slide in the direction of commanding the PCA to extend, the elevator to trailing edge up and nose up (trying to override a jammed slide).

j. The servo sleeve's internal surface contains some circumferential corrosion stain bands. The position of those bands is consistent with the servo slide at a possible position off neutral (Figure 38).

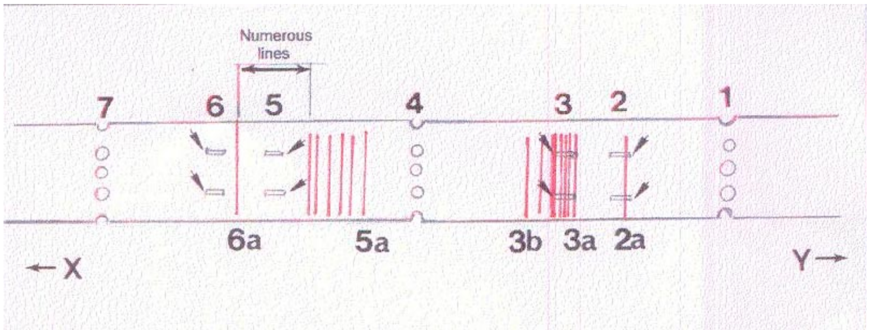

Figure 38 Developed view of sleeve internal surface with the corrosion stain bands (shown in red lines). Arrows "X" and "Y" denote the spring and input end respectively. The sleeve ports denoted by numbers 1 to 7.

2. Inspection of MH #3 revealed that this part of a manifold was missing the input portion of the manifold (which is believed to be MH #4). Although this manifold was subjected to impact forces high enough to fracture the input portion, all the components inside were still intact and in their proper position.

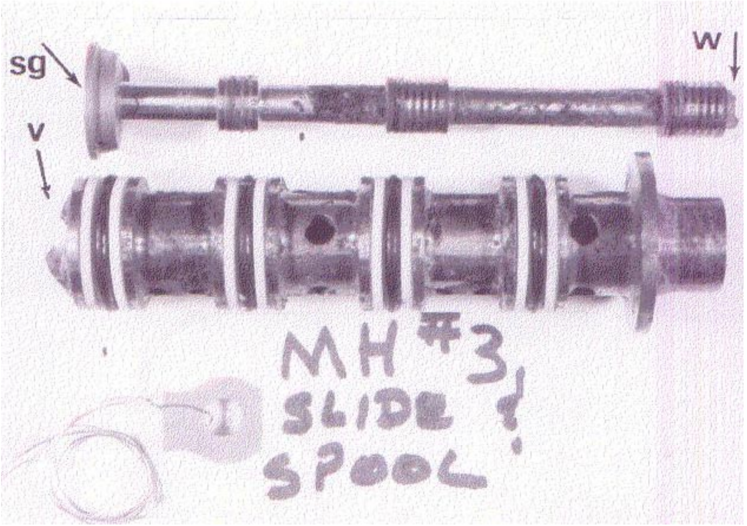

Figure 39 Parts of the slide and sleeve of MH #3

3. Examination of the recovered five bell cranks revealed that the shearing direction of the rivets in bellcrank #3 and #4 is consistent with the direction of pulling on the control column in the cockpit which might be the result of the crew trying to override a jamming condition. Also, one of the shear rivets in bellcrank #5 has a circumferential crack (denoted by the “c” arrow in Figure 40) in a different plane other than the fracture plane. That could be a potential for a bellcrank shear. The NTSB, FAA, and Boeing are studying the reason for the reported unexplained bellcrank shears that caused the FAA to issue two Airworthiness Directives AD2000-17-05 and AD2001-04-09 on August 2000 and March 2001 respectively.

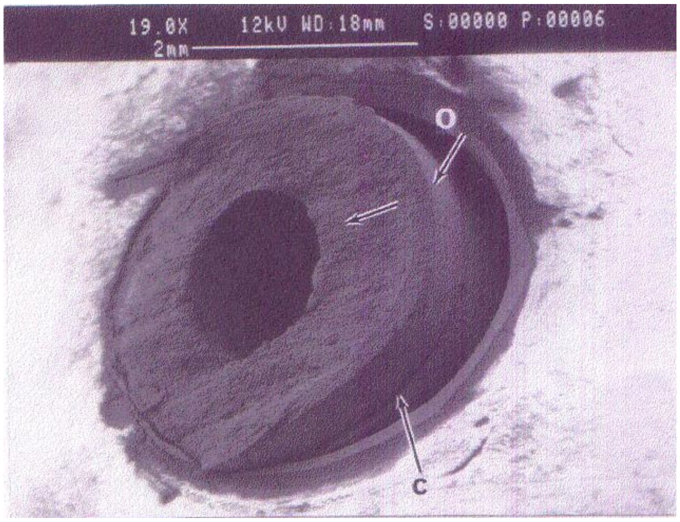

Figure 40 Non-fracture plane circumferential crack, bellcrank #5.

4. Examination of the input push-pull rods of the right elevator between the middle bellcrank (bellcrank #4) and inboard bellcrank (bellcrank #5) (Figure 41) revealed that this rod was subjected to the smallest amount of deformation, which is not consistent with the two bell cranks sheared in opposite directions unless one of them was sheared Before impact and the other was sheared during impact. Note that this part of the push-pull rod was still connected to bellcrank #4 and bellcrank #5 when it was recovered.

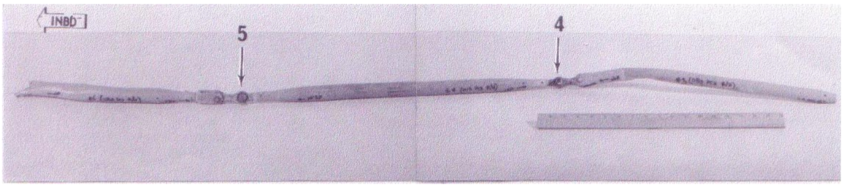

Figure 41 Push-Pull rod between bellcranks #4 and #5

Conclusion:

As noted above, the three right elevator bellcrank assemblies were recovered; two bellcranks rivets were sheared in one direction, one in the opposite direction. This evidence alone indicates that they were not damaged by a single, simultaneous force such as would arise on impact with the ocean. In addition, the right outboard elevator PCA was recovered and revealed that the pin holding the spring guide to the slide had been sheared and that the spring had looped over the spring guide. For the reasons described above, it appears that this damage occurred before the impact with the water and is consistent with a jammed servo valve.

2.3.3.11 Analysis of the Events During the Dive:

The following is a compilation of observations supported by the FDR data:

- After the autopilot disconnect just before the event, both elevators moved slightly down (airplane nose down) with a slight airplane pitch change (nose down).
- FDR data showed that on October 30, 1999, the autopilot for the accident airplane was disconnected three times during the leg between New York and Los Angeles. Each time, the elevators showed a slight downward movement which is consistent with a single elevator PCA jam condition on the right elevator. Such a jam could have occurred any time after the last “A” check on the airplane.
- The anomalies found in one of the recovered elevator PCA valves support the possibility of dual PCA jam failure.
- After the autopilot was disconnected, the two elevators moved on a schedule close to that which would result from a dual elevator PCA jam failure. This could indicate the occurrence of a second PCA jam condition on the right elevator.
- The speedbrake lever was deployed and the throttle levers were retarded to assist in decelerating the airplane.
- Upward movement of the unaffected left elevator near the end of the dive, could indicate a successful pull on the control column.
- During the descent, the engine low oil pressure lights illuminated coincident with an extremely low and abnormal Engine Pressure Ratio (EPR) reading. These readings

could indicate (or could have been interpreted to mean) a dual engine flameout. According to the Boeing 767 checklist, to relight the engines during flight, the fuel control switches should be moved to the CUTOFF position, and then the engine inflight start procedure should be initiated.

The following considerations could explain why recovering from the dive was not accomplished immediately upon entering the dive:

- There were no visual or aural warnings in the cockpit alerting the crew of a dual PCA failure.
- There was no flight crew checklist for such failure, and the cockpit crew had no previous training to deal with such failure
- The stabilizer trim might have been inhibited in the nose up trim direction because of the forward movement of the control column (~ 2.5 degrees of control column forward movement).
- The force necessary to control the left elevator is significantly higher than the normal column force.
- Excessive force applied to the right column can disconnect both columns from each other through the front and rear override connections; therefore, the left elevator will not be controllable from the right column.
- High rate of force application on the right column could have a significant effect on elevator controllability.
- With increasing speed and with the high rate of descent, altitude flags were in view most of the time on both sides. The speed flag and instantaneous vertical speed (IVS) flags would come in view several times during the event.
- The airplane was suffering from severe buffeting condition through most of the dive because of the extremely high speed.
- The vertical load factor (g forces) varied extensively through the dive from a negative value to greater than +2.4 g's.
- The airplane load factor reached a value in excess of 2.4 during the recovery from the dive. With such a high load factor and high speed (much greater than the maximum operating speed (MMO) which is 0.86) Mach, there is a very high possibility of airplane disintegration. The location of the left engine in the west field far from the main wreckage field and being in an intact condition compared to the remaining wreckage highly support this possibility. A trajectory analysis of the engine indicates that the left engine was most probably separated from the airplane just after the recovery from the dive.

2.3.4 Conclusion

The analysis presented in this document shows that a dual PCA failure is consistent with the known and predicted behavior of the airplane and all of the recorded data concerning the accident. Although a dual PCA failure cannot be confirmed; however, it must be considered as a plausible cause of the accident.

2.4 ATC/Communications & Radar Data Analysis

2.4.1 Overview

Information from the ATC transcript, radar data and interviews with radar controllers were analyzed. The objective of the analysis was to study the performance of the EgyptAir flight 990 crew, the Air Traffic Controllers performance and other factors, which might have an impact on the EgyptAir flight 990 accident. Analysis indicated that no irregularity has been observed with the performance of the crew of EgyptAir flight 990. Analysis showed a number of irregularities in the ATC handling of the flight. In addition, the analysis showed that several airplanes were identified in the ATC transcripts, yet no radar data was found for this airplane. This suggests that other objects might have existed in the vicinity of EgyptAir Flight 990.

Radar data were also used to calculate the airplane flight path and the airplane performance parameters. It is convenient to express the position of the airplane in rectangular Cartesian coordinates. The Cartesian coordinate system used in this analysis is centered at the ACK (Nantucket) ASR-9 radar antenna and its axes extend East, North, and up from the center of the Earth.

The analysis of radar primary data showed returns forming several continuous flight paths. Based on the limited information provided to the Egyptian team, it is believed that these paths are formed by real objects meeting the EgyptAir 990 Flight path, with high ground speeds (about 1.4 Mach number).

A trajectory analysis relating to the left engine was conducted based on available radar data. It was clear that the left engine separated from the airplane well before the fuselage impacted the water and that it hit the water at a much lower speed than the fuselage.

2.4.2 ATC/Communications Analysis

Based upon the ATC transcript and the reported interview with the R68 radar controller, the Egyptian team believes that the procedural ATC irregularities in the handling of EgyptAir Flight 990 are related to the accident.

The pilot report[33] from Royal Jordan Flight 262 raises a question about the route of EgyptAir 990 through warning area W105. The ZBW logs indicated that W105 was active during this period. In addition, an "Inner Marker" signal was recorded at 1050:17 and remained to the end of the FDR recording. There is no explanation as to why or from what source this signal was generated.

Another obstacle was that some of the essential documents recommended by ICAO were considered classified by the U.S. government and were restricted from the Egyptian team. The remaining radar data received from NTSB were either not complete or were in conflict with each other. Consequently the ATC analysis could not be conducted in a comprehensive manner.

In spite of the above and in the light of the available documents, the analysis of ATC portion of the investigation developed the following conclusions:

A - The performance of MSR 990:

- ☐ No deviations from the air traffic clearance were observed.
- ☐ The original route of Egypt Air 990 was Shipp, Linnd, Lacks and Dovey until 01 35:52 when R86 instructed Flight 990 to climb and maintain FL 330 cleared direct Dovey. This clearance directed the flight through W105 and W506.

B - The ATC performance:

EgyptAir 990 did not receive proper ATC service as shown by the following:

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[33] This flight departed from JFK approximately three hours before EgyptAir 990 and followed a similar departure route. The incident took place at approximately same location as the Flight 990 accident.

- EgyptAir flight 990 had a valid flight plan even though it was not entered in the ATC system by FAA controller.

- At 12 56:41 and 05 56:43, both ZNY and LC agreed together to clear Flight 990 to FL 310 and not FL330 as the filed flight plan.

- At 01 24:48, ZNY asked N90 ”doesn’t any body know over at the tower that they gotta put these flight plans back in.”

- At 01 25:38, ZNY controller R 66 mentioned that he did not know how to enter the data correctly.

- 01 32:15, R66 stated, “nobody typed in the Egypt Air but they did type in the LACSA.”

- R66 could not find the flush strip of Flight 990 before 01 29:00. As part of the transition to DARC at 04 30 00, all flight plans stored in the Host/NAS, including EgyptAir 990's flight plan, were printed out at the appropriate sector.

- Sector R 86 radar controller indicated that she usually works only day shifts and that is rare for her to work an evening or midnight shift.

- The original flight route assigned for Flight 990 was Shipp/Linnd/Lacks/Dovey, which was outside all the warning areas.

- Flight 990 was instructed by R86, before reaching Linnd, to go direct to Dovey which crossed warning areas W 105 A and W 506.

- It is clear that the EgyptAir 990 flight was not under Air Traffic Control from 01 47:18 UTC to 01 54 00.

- The R86 did not recognize that the data block for EgyptAir Flight 990 went to the xxxx, then converted to coast status and finally showed as primary returns only. As a result, she did not take any action before 06 54 00 when she started to, call the Flight 990.

- ZNY logs indicated that warning areas were not active while ZBW logs indicated that W 105 was active during part of that night. FACSFAC VACAPES indicated that the W 386 was the only activated area on that night.

- The flight strips for EgyptAir 990 did not include written altitude and time as required by the flush procedure.

- EgyptAir 990 was the only flight that was instructed to go direct to Dovey during that time.

The Egyptian team effort was hindered by the absence of much ATC data that had been requested from the NTSB and the FAA.

2.4.3 Radar data analysis

2.4.3.1 Conversion of Radar Data to Common Cartesian coordinate system

To calculate EgyptAir 990's flight path and the airplane performance parameters from the radar data (such as ground speed, track angle, rate of climb, etc.), it is convenient to express the position of the airplane in rectangular Cartesian coordinates. The Cartesian coordinate system used in this analysis is centered at the ACK (Nantucket) ASR-9 radar antenna, and its axes extend East, North, and up from the center of the Earth. The data from the North Truro, Massachusetts (NOR), Riverhead, New York (RlV), Gibbsboro, New Jersey (GIB) and the ASR-9 radars at Nantucket, Massachusetts (ACK) are all converted into this coordinate system for plotting and performance calculations. Latitude and longitude coordinates, values of range and azimuth are transformed into this coordinate system using the WGS84 ellipsoid model of the Earth.

Following Figures show the EgyptAir 990 flight path in X-Y Cartesian coordinates using the secondary and primary returns (Plan view and altitude time history)

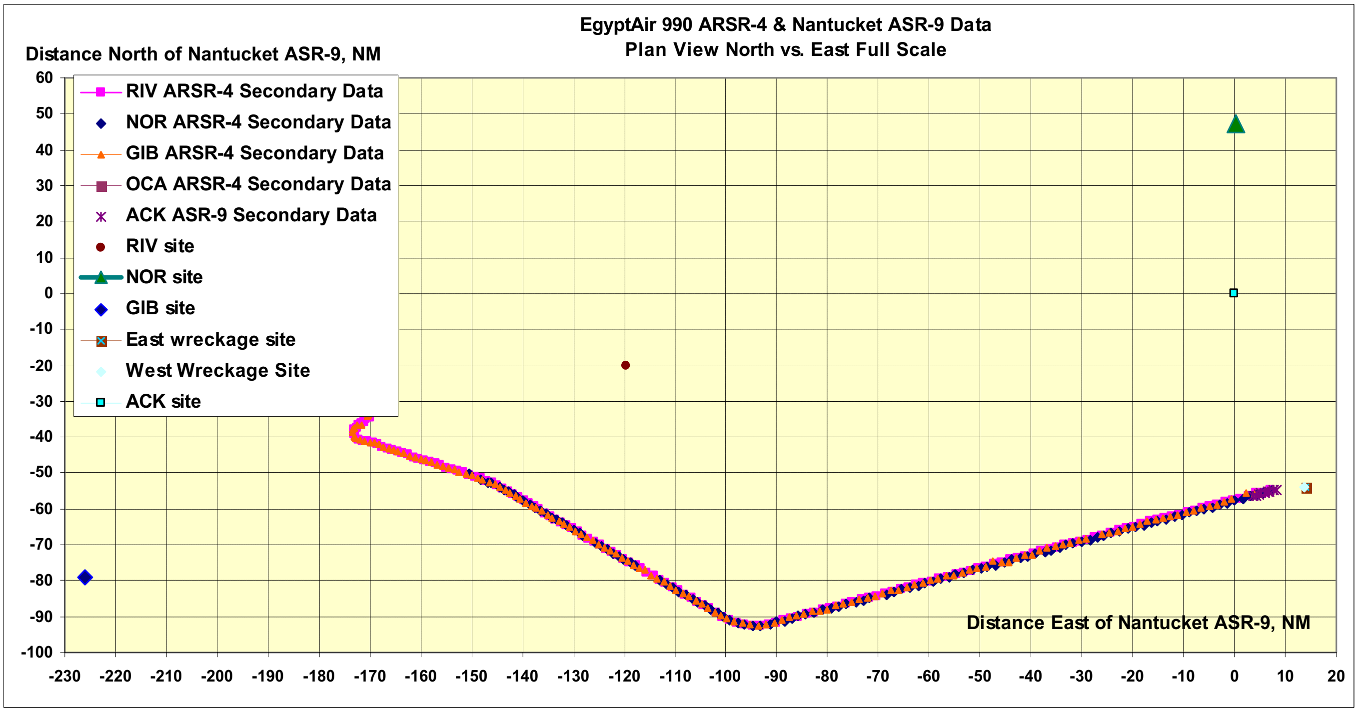

Figure 42 EgyptAir Path (Secondary returns) & Radars and wreckage sites

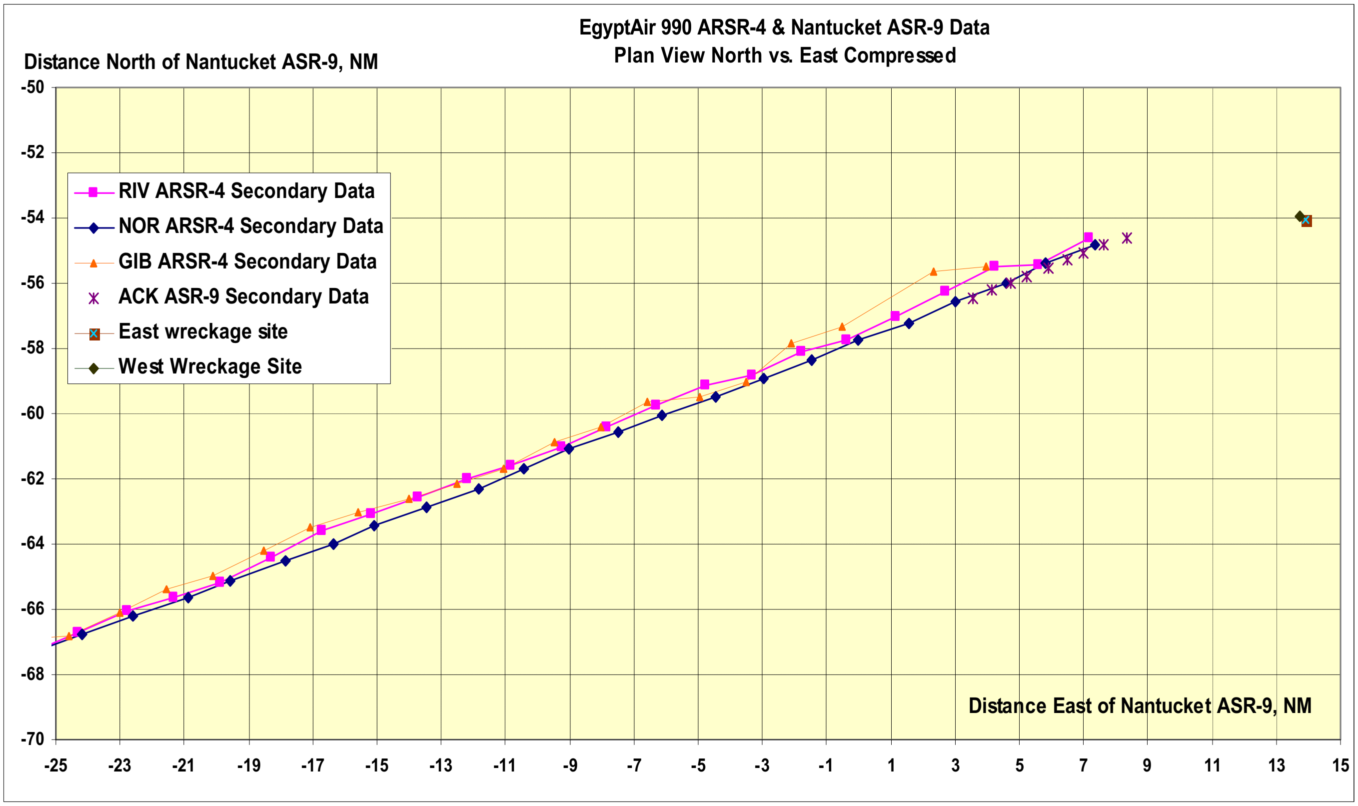

Figure 43 EgyptAir Path (Secondary returns) & wreckage sites Compressed View

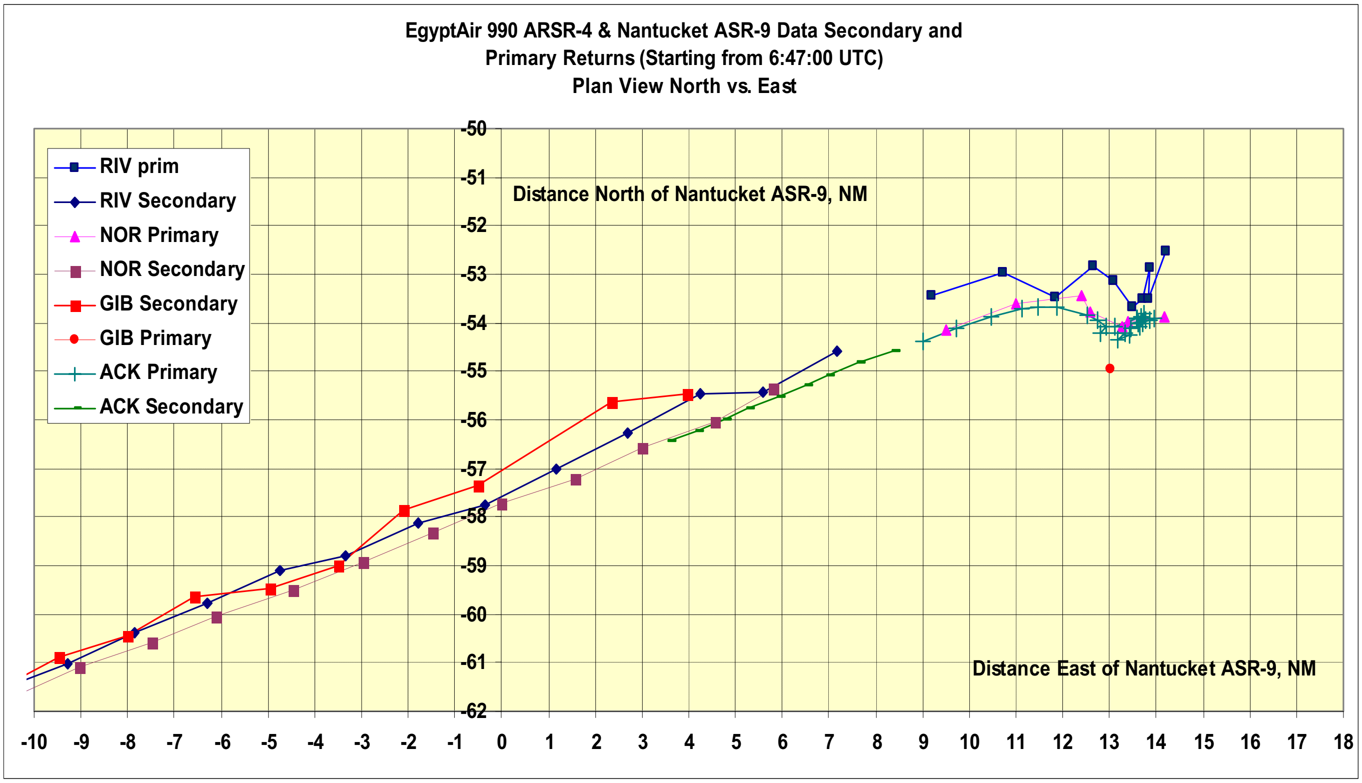

Figure 44 EgyptAir Path (Secondary and primary returns)

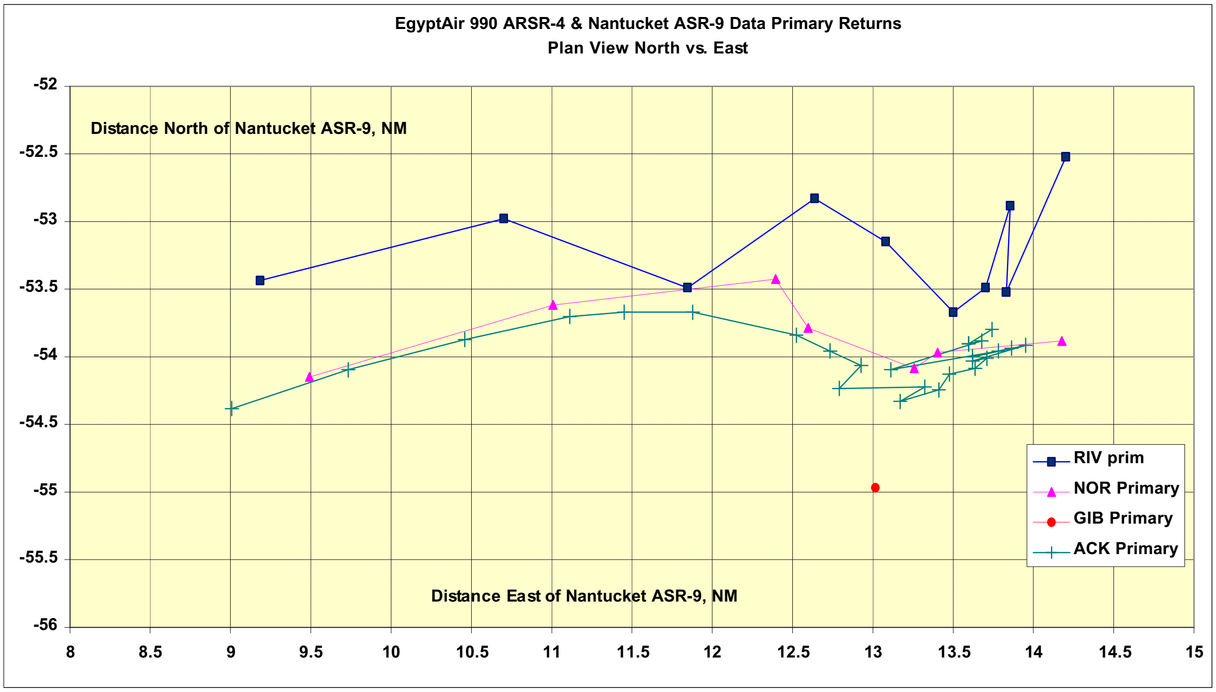

Figure 45 EgyptAir Path (Secondary returns) Plan view

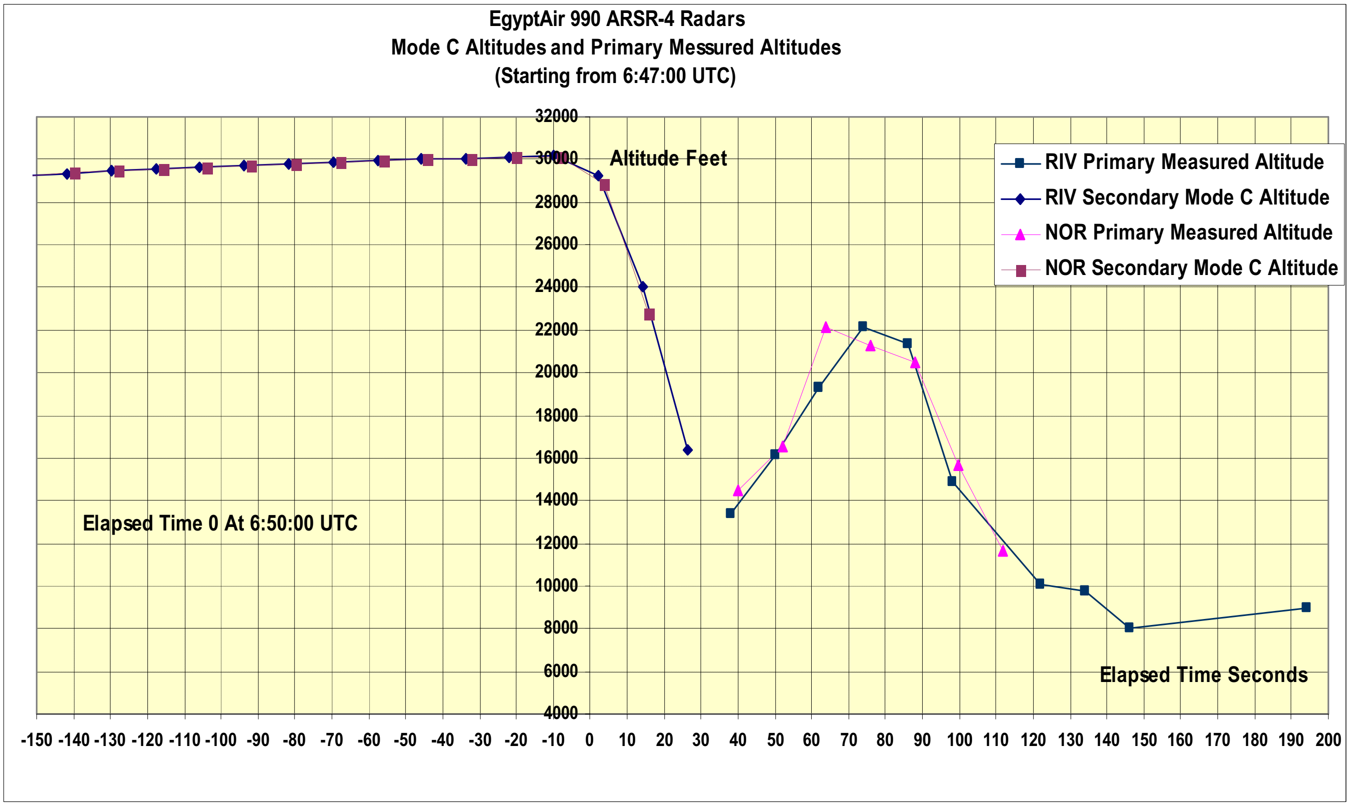

Figure 46 EgyptAir Altitudes (Secondary and primary returns) Altitude history view

2.4.3.2 Objects Other than EgyptAir Flight 990:

Figure 47 is constructed using the primary data from Riverhead (RIV) radar. The analysis of RIV primary data showed returns forming three continuous flight paths. Based on the limited information provided to the Egyptian team, it is believed that these paths are formed by real objects crossing the EgyptAir 990 flight path, with high ground speeds (about 1.4 Mach number).

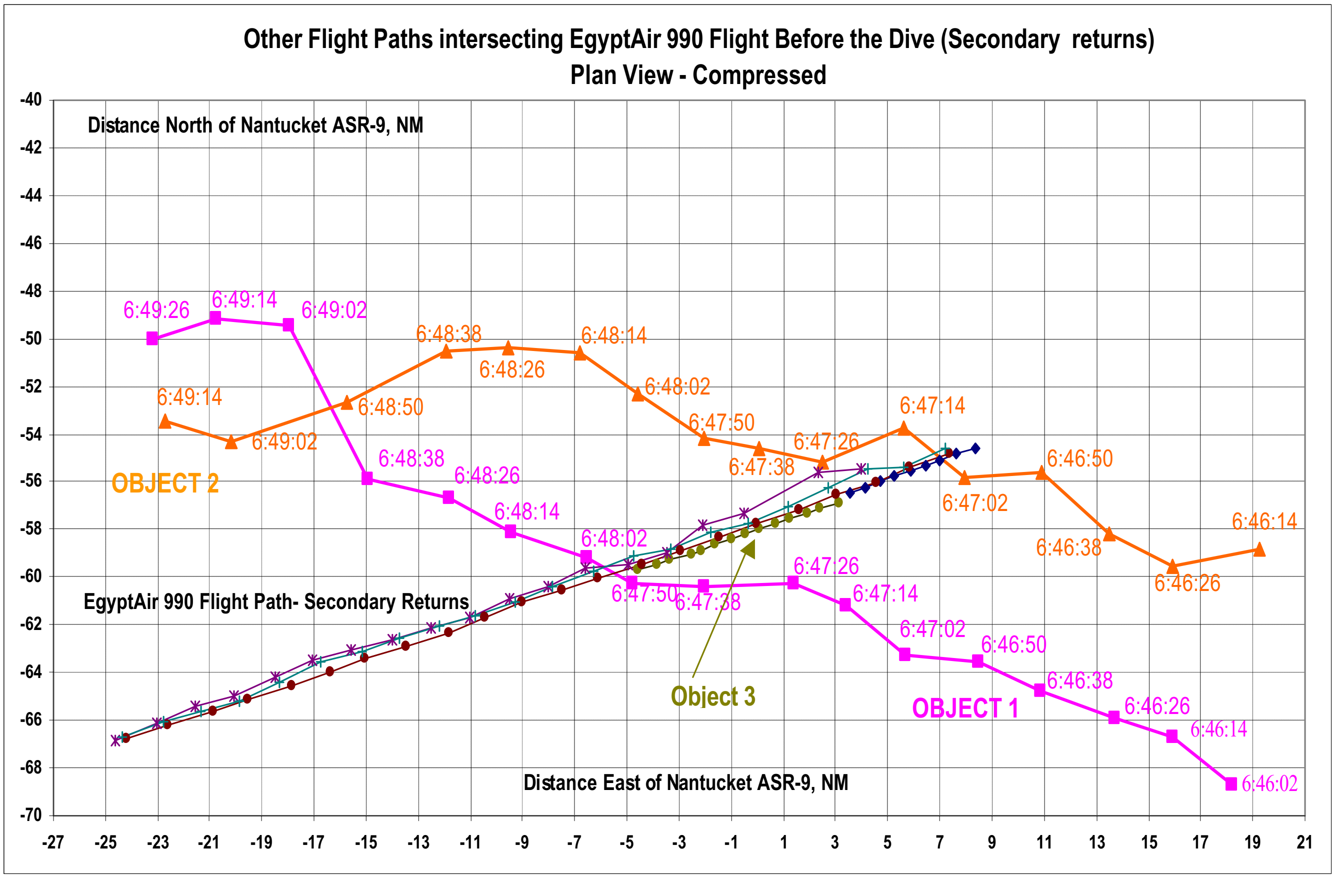

Figure 47 Continuous flight path returns meeting EgyptAir Flight 990

2.4.3.3 Left Engine Trajectory Analysis:

When the wreckage of EgyptAir 990 was found, there were two distinct wreckage locations. The fuselage and most of the rest of the airplane were found in one location and the left engine and related parts were found in a second location. The left engine was found approximately 1200 feet East of the main wreckage site. In addition, the left engine showed significantly less impact damage than the wreckage found in the East recovery area. It was clear that the left engine separated from the airplane well before the fuselage impacted the water and that it hit the water at a much lower speed than the fuselage. A series of trajectory analyses were used to determine the location of separation of the left engine from the rest of the airplane. A complete discussion of the analysis is contained in Appendix A-6.

3.0 CONCLUSIONS

3.1 Findings

1. EgyptAir Flight 990 airplane was operating under the ECAA regulations with no violation.

2. Accident airplane Maintenance Records indicated that all relevant maintenance work had been duly carried out. Scheduled maintenance checks are approved by the ECAA (MSR Operations Specifications D88), and are in accordance with the Boeing 767 Maintenance Planning document (MPD). Also data from EgyptAir's System Reliability Report showed no unacceptable maintenance trends or discrepancies.

3. For both the active crew and the cruise crew, there were no reported history of psychiatric consultation nor any reports regarding their behavior, either professionally or in groups, throughout their career as pilots.

4. Psychiatric Analysis for the First Officer Gamil El Batouty indicated that there was no evidence that he was suffering from depressive disorder or bipolar illness. Analysis also indicated that there was no evidence of schizophrenia, alcohol abuse or any psychotic condition.

5. The analysis showed that there was no evidence of a fight or struggle among the crewmembers during the dive; on the contrary, the evidence indicated crew cooperation to recover airplane control. The crew attempted to control the airplane and did not question the RFO's behavior. There was also no effort to incapacitate the RFO or to restrain him.

6. The initial movement of the elevator surfaces at the beginning of the dive were less than one third of the full elevator system capability.

7. The actions performed in the cockpit for EgyptAir 990 (when synchronized with the CVR/FDR data) can only be accomplished by at least three persons.

8. A dual PCA valve jam failure on the right elevator surface is consistent with all of the available recorded information. Cockpit instrumentation on the B-767 does not include any annunciations that would indicate an elevator PCA jam or failure.

9. Primary flight control inputs and applied forces are not recorded by the FDR.

10. When the autopilot was disconnected, the behavior of the elevator on EgyptAir 990 throughout the 25 hours of recorded data was consistent with a pre-existing right elevator PCA failure and no such indication was found on a sister Boeing 767.

11. At the same time that the elevators showed a split condition, the inboard and the outboard ailerons showed behavior that was not consistent with the Boeing 767 aileron system design. Analysis showed that this behavior could not be due to rolling or side slip movements (using the available data for ailerons hinge moments coefficients).

12. Analysis indicated that the rolling moment that would have been caused by the recorded split elevator is greater than could have been controlled by the recorded aileron deflections. It is also shown that the recorded pitch angles are consistent with some or the entire right elevator haven broken off the airplane at the beginning of the alleged elevator split.

13. The analysis of the ground test results revealed that the elevator control system on the test airplane did not behave exactly as was predicted by the Boeing engineering data.

14. Analysis of the E-Cab simulator testing showed that the behavior of the simulator was unlike the airplane in several key aspects.

15. An analysis of the damage to one of the elevator PCA's showed that the observed damaged could not have occurred during impact with the water.

16. A dynamic analysis of the elevator control system showed that forces sufficient to separate both the front and rear override connections are attainable, although a static analysis shows that higher forces are needed for separation.

17. The metallurgical analysis of the recovered elevator control system components indicated that several of the components had failure patterns that were inconsistent with impact damage.

18. Analysis of ATC transcript, radar data indicated that there was no irregularity regarding the performance of the crew of EgyptAir 990.

19. Analysis of ATC transcript, radar data showed a number of irregularities in the ATC handling of the flight.

20. Analysis of ATC transcript and radar data showed that several airplanes were cited in ATC transcripts but no radar data was found.

21. The analysis of radar primary data showed returns forming several continuous flight paths meeting the EgyptAir 990 flight path, with high ground speeds (about 1.4 Mach).

22. The Left Engine Trajectory Analysis indicated that the left engine separated from the airplane well before the fuselage impacted the water and that it hit the water at a much lower speed than the fuselage.

3.2 Probable Cause

Annex 13 does not state a probable cause unless sufficient conclusive evidence is available to substantiate a theory as a probable cause.

In compliance with the above, the Egyptian Investigation Team establishes that while there has been extensive examination of various plausible theories, the evidence is not sufficient to identify one particular set of events as the cause of the accident. There are, however, two matters as to which some conclusion may be drawn: First, there is no evidence to support a conclusion that the First Officer intentionally dove the airplane into the ocean in fact, the evidence available refutes such a theory, a determination confirmed by expert medical opinion, technical and human performance analysis.

Second, the accumulation of evidence showing anomalies in the elevator system of the accident airplane makes a mechanical defect a plausible and likely cause of the accident. The NTSB spent over four years investigating the accident of a U.S. carrier, USAir, when a Boeing 737 crashed near Pittsburgh, even though the suspect valve in the rudder system showed no physical signs of a defect or jam. In this accident, the ECAA has uncovered specific physical evidence that may show a defect in the elevator system of Flight 990. Moreover, both the FAA and Boeing agree that the shearing of elevator bellcrank rivets -- an issue that the ECAA has urged to be explored in greater detail -- can cause an uncommanded dive. These circumstances justify a conclusion that a mechanical problem is a plausible theory that deserves further investigation.

The possibility remains, however, that the RFO intentionally maneuvered the airplane to avoid a collision or to respond to some other emergency. No substantial evidence supporting or negating such a possibility has been uncovered. The most significant evidence on this issue -- the radar data -- is inconclusive because the Relevant Authority will not release information necessary to analyze thoroughly the potential, and as yet, unidentified radar targets.

Appendix A-1
AIRPLANE PERFORMANCE

It has been shown by Bach and Wingrove that the performance of an airplane can be reconstructed from recorded radar data. They showed, using the equations of motion and basic aerodynamic and mass data for the airplane, that almost all relevant flight parameters can be retrieved. The first step in such a reconstruction is to smooth the inherently noisy radar data.

Regardless of the source of the radar data, the data must be smoothed before it is processed. Calculating the flight parameters with unsmoothed radar data is almost certain to result in airplane performance that is impossible for a real airplane to achieve. To accurately reconstruct the airplane performance parameters from recorded radar data, that data must be smoothed. The accident investigator must decide how the data are to be smoothed and, after the data are smoothed, how the flight parameters should be calculated. Too little smoothing and the resulting airplane performance will most likely be unrealistically abrupt and sometimes impossible for a real airplane to achieve. Too much smoothing and the character of maneuvering flight will be lost.

Because of the abrupt maneuvers the airplane was believed to perform in this accident, a minimal amount of smoothing is appropriate. For this analysis, a seven-point moving quadratic curve fit was chosen as the best compromise between realistic airplane performance and abrupt airplane maneuvers. A curvilinear reconstruction analysis was used so that the vertical and horizontal turns would be more accurately represented.

The airplane performance that results from this analysis is presented in Figures A-1.1 through A-1.7. This performance analysis is based on the recorded radar data, in particular the primary returns recorded by the Nantucket ASR-9 radar facility, which was supplemented with the estimates of altitudes from the Air Force long range radar. These altitude estimates were confirmed as feasible using an analysis of possible airplane performance between the radar returns and the crash site. The flight path terminates at the East Recovery Site.

Also critical to this analysis is the estimate of the winds and temperatures at altitudes between 31,000 feet and surface of the ocean. For this analysis, the average of the four most appropriate radiosonde reports (as described in Paragraph 1.7.2) was used as the wind and temperature profile.

The maximum Mach number is approximately 0.98, which occurs at an altitude of approximately 26,000 feet MSL. Also, the maximum load factor is approximately 3.4, which occurs shortly after the FDR ceases to record data. Flight path reconstructions cannot predict negative load factors. If such a condition occurs, the reconstruction cannot distinguish the difference between a negative load factor pushover and an inverted pull as on the top of a loop. The mathematics that describe these maneuvers default to the inverted pull; therefore, the calculated load factors in the reconstruction never show a negative value.

This analysis also shows that the angle of attack increases to a very high number at the top of the climb. This suggests that the airplane stalls at this time. This is confirmed by the calculated calibrated airspeed of under 100 knots at that time. That airspeed is well below the level flight stall speed. The plots for the reconstructed load factor and angle of attack stop after the first stall. The reason for this is that the reconstruction analysis cannot accurately predict post-stall airplane performance, so any results presented in this regime would be misleading.

The results of this analysis are used in the analysis to determine the point at which the left engine departs the airplane.[34]

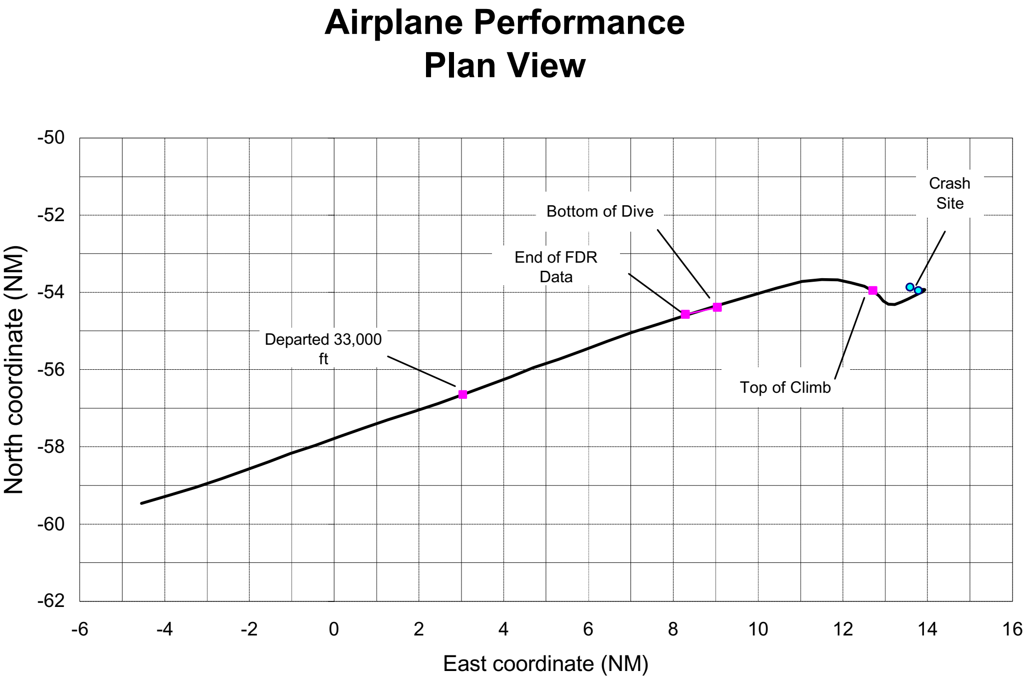

Figure A-1.1. Overhead View of Reconstructed Flight Path.

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[34] References:

Bach, R.E. Jr. and Wingrove, R.C., “Equations for Determining Aircraft Motions from Accident Data,” NASA TM-78609, 1980.

Winn, R.C. and Slane, J.H., “A Curvilinear Approach to Flight Path Reconstruction From Recorded Radar Data,” AIAA Paper 2001-0411, January 2001.

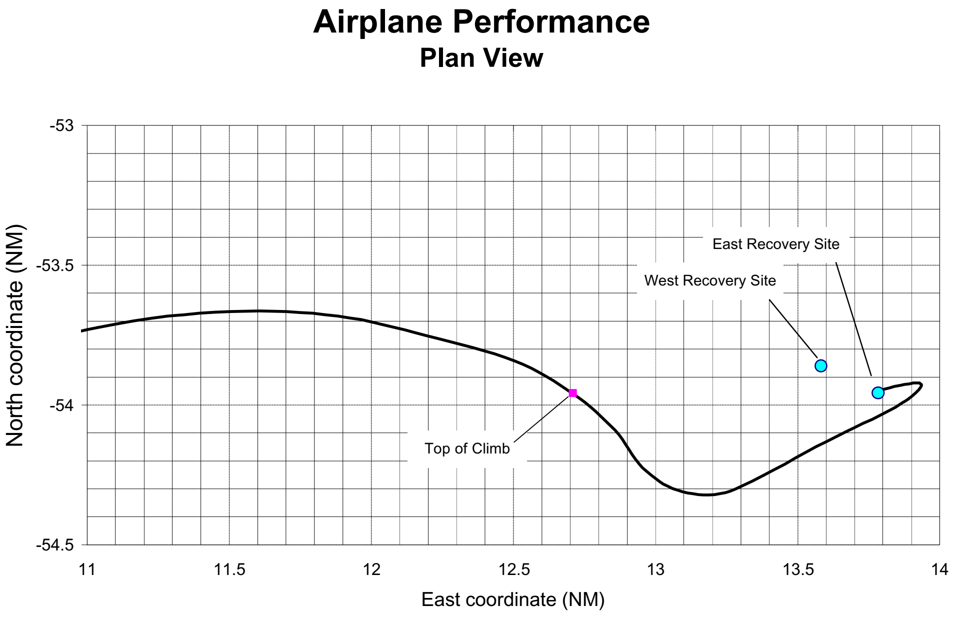

Figure A-1.2. Overhead View of Final Portions of Reconstructed Flight Path.

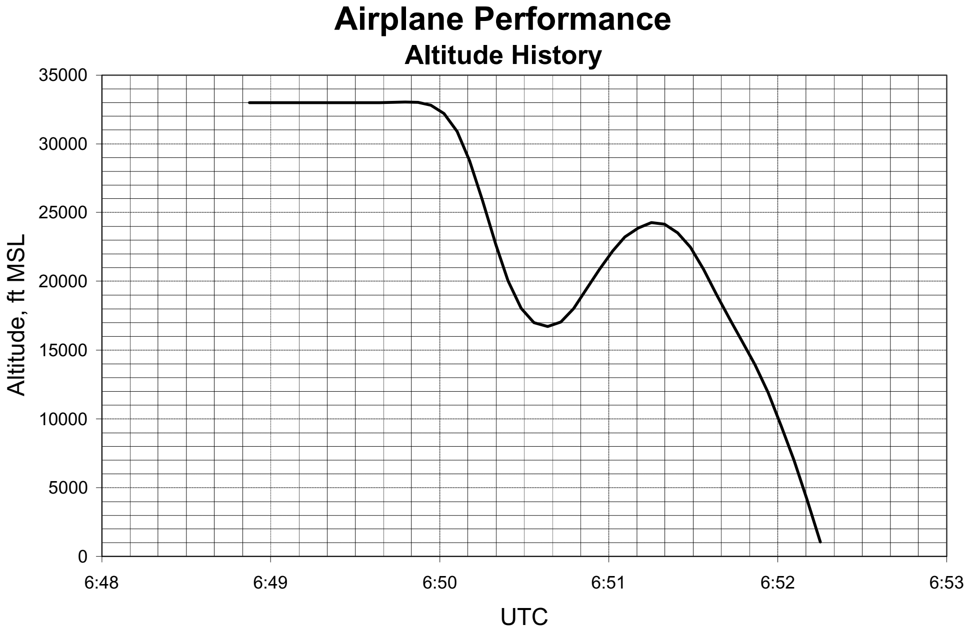

Figure A-1.3. Reconstructed Altitude History.

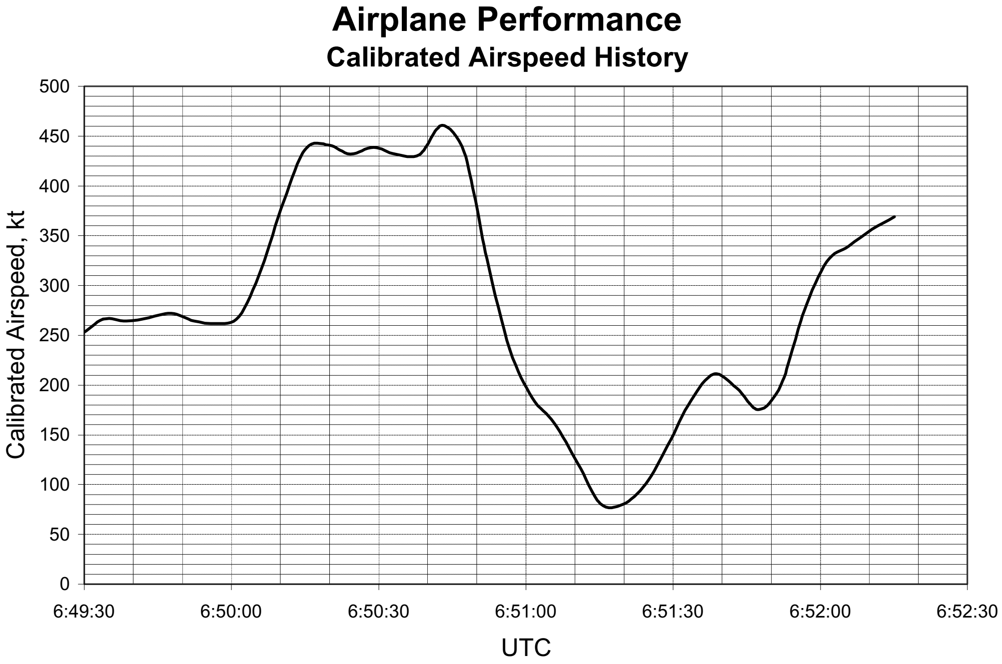

Figure A-1.4. Reconstructed Calibrated Airspeed History.

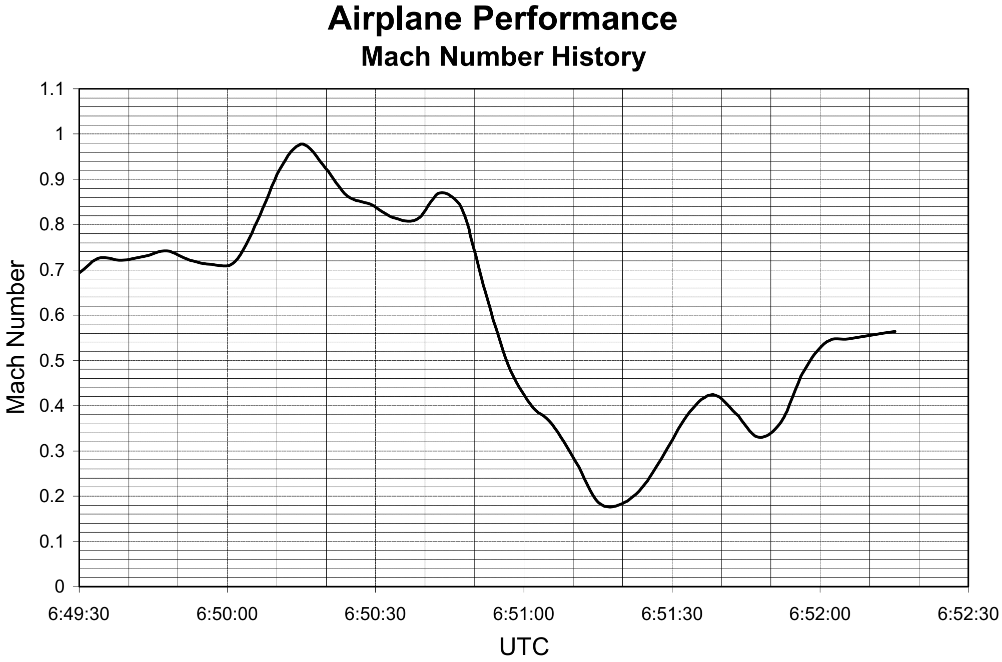

Figure A-1.5. Reconstructed Mach number History.

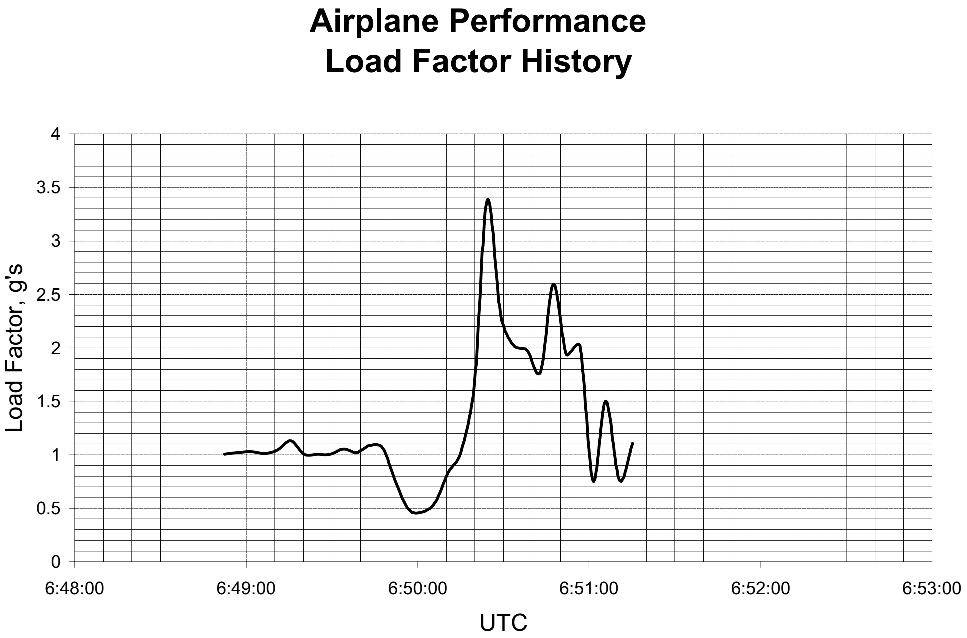

Figure A-1.6. Reconstructed Load Factor History.

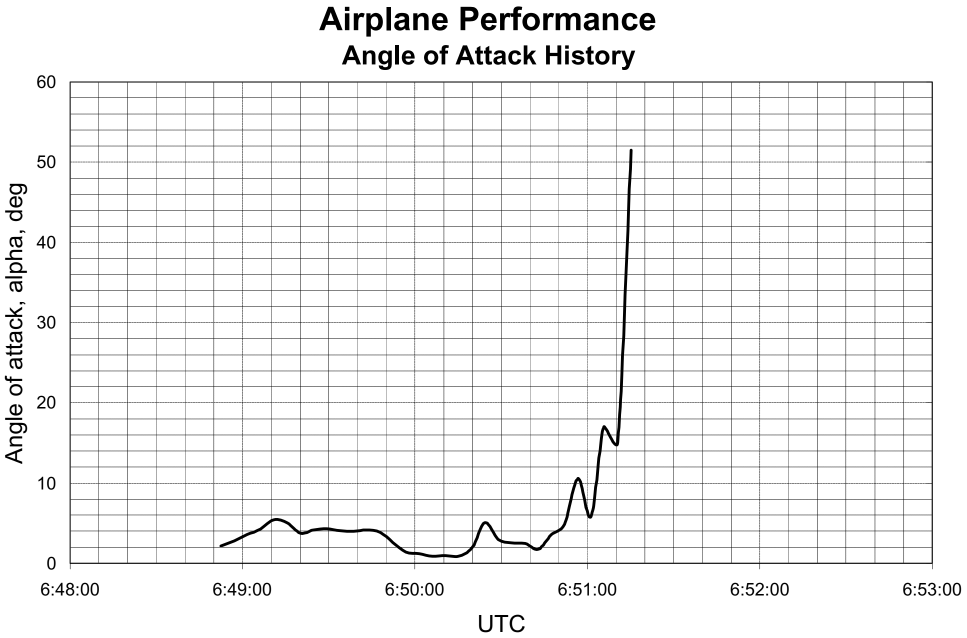

Figure A-1.7. Reconstructed Angle of Attack History.

Appendix A-2.
Detailed Investigation into the Possibility Of the Inflight Loss of the Right Elevator:

At approximately 1:50:21 EDT, the FDR recorded a sudden and immediate change in the position of the right elevator from an essentially neutral position to over 3 degrees TED, while the left elevator continued to move approximately 4 degrees in the opposite, TEU, direction. This information was recorded at about .99 Mach,[35] a speed far in excess of the available data for the Boeing 767.

Differential elevator deflection such as shown on the FDR will induce a rolling moment. The first session of Boeing E-Cab simulations did not include this effect because the elevators were constrained to operate symmetrically. To address this shortcoming, an approximate mathematical analysis of this effect was conducted. The analysis is approximate because detailed stability derivative information on the B. 767 is not available; therefore, the analysis was based on the sizes and locations of the various components. Although the analysis is approximate, it shows that the rolling moment due to a differential elevator deflection such as that shown on the Flight 990 FDR is significant. Referring to the last 15 seconds of the FDR data no significant roll was recorded, thus raising a question of whether the elevators were actually split. The data raises the further possibility that the right elevator had departed the airplane by that time.

This analysis consisted of two investigations that used control surface and data from the EgyptAir 990 FDR. The first investigation estimated the amount of aileron deflection needed to counter the rolling moment produced if there is a split in the left and

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[35] Reference: NTSB, Exhibit 13 Aircraft Performance, and Group Chairman's Aircraft Performance Study. Note that the FDR elevator data only shows what is being recorded by the sensors and does not -- by itself -- indicate either the condition of the elevator system or the position of the control columns.

right elevator deflection of the magnitude shown on the FDR. In the second analysis, a pitch simulation was performed to investigate the pitch attitude produced by the elevator deflections recorded by the FDR

If the elevators have a differential deflection as shown by the FDR data in Figure A-2.2, they will produce unequal lift on the left and right sides of the tailplane resulting in an airplane rolling moment. The methods of Roskam (Design, Part VI, Roskam Aviation and Engineering Corporation) were used to estimate the lift on the horizontal tail. Basic lift for the left and right tailplane was calculated using the angle of attack as recorded by the FDR. The elevator was treated as a plain flap and the incremental lift on the left and right surfaces was calculated. These lifting forces were then multiplied by a moment arm assumed to be acting at one-third the elevator half span. This resulted in a net rolling moment due to the differential deflection of the elevators. One time slice 1:50:28 EST (time = 28 seconds on the x-axis), was chosen to make these calculations. The relevant parameters are listed below:

$$\begin{aligned}
&\mathrm{Vcas} = 456\ \mathrm{kt} \\
&\mathrm{M} = 0.93 \\
&\delta_{e_L} = -3.69\ \mathrm{deg} \\
&\delta_{e_R} = 3.16\ \mathrm{deg} \\
&\alpha = -9\ \mathrm{deg} \\
&\phi = 4.4\ \mathrm{deg}
\end{aligned}$$

The rolling moment coefficient for the inboard ailerons was then estimated. The outboard ailerons were assumed to be locked out at this high airspeed. Figure A-2.2 demonstrates that the roll angle was small during this time period. The airplane was well controlled in the roll axis; therefore, the rolling moment due to elevator would be balanced by the rolling moment from the ailerons. Equating the rolling moment due to differential elevator deflection with the restoring rolling moment due to ailerons, a differential aileron deflection was calculated. The result is $\delta_a = 26\deg$

However, if it is assumed, by this time step, that the right elevator is either gone or streamlined and is producing no incremental lift, then the aileron deflection needed to counteract the rolling moment due to the left elevator is $\delta_a = 4.4\deg$

FDR data for aileron deflection is shown in Figure A-2.1. At this time step, the differential aileron deflection was 6.5 degrees, significantly smaller than the 26 degrees predicted by the split elevator analysis, but very close to 4.4 degrees predicted by the streamlined right elevator analysis.

This roll analysis suggests that an elevator split did not occur, but elevator deflection also controls pitch. Therefore, a longitudinal simulation of the motion after 1:49:53 (time = -7 seconds) was performed. Models for lift, drag, and pitching moment were derived using the methods of Roskam. Inputs for elevator deflection and stabilizer incidence were taken from the FDR data. A full six-degree of freedom simulation was performed assuming that all lateral directional forces and moments were zero. The resulting pitch angle history is shown in Figure A-2.3. With the elevator set as recorded on the FDR, the simulation continues to pitch down an additional 6 degrees beyond that recorded by the FDR. This additional downward pitch is due to the nose down pitching moment produced by the right elevator.

The results shown in Figure A-2.4 are calculated assuming that the right tailplane was no longer producing a lift increment due to deflection of the right elevator. The maximum nose down pitch angle agrees very well with FDR data, and the simulated pitch begins to recover very closely in time to the FDR pitch attitude.

The effect of the pitching moment due to differential elevator deflection was also supported using data gathered during the second session of E-Cab simulations. During the second session, the programming of the simulator had been changed to model the differential elevator deflection. Plots extracted from the data recorded at the second E-Cab simulator session are shown in Figures A-2.5 and A-2.6. This example was recorded during a run in which the right elevator was deflected down approximately 5.5 degrees of right elevator deflection and the left elevator left to pilot control. Notice that differential aileron deflections of over 40 degrees are needed to keep the roll angle near zero. During the time of the alleged split elevator, the maximum differential aileron deflection recorded on the FDR was approximately 13 degrees (with the exception of one second at almost 20 degrees) and the average was about 6.5 degrees. These results can only be explained if the elevator did not actually produce the calculated rolling moment. Further, the positive load factor that was recorded on the FDR was due to the position of the stabilizer with very little, if any, input from the elevator. Also, severe damage to the elevator would explain the inability to fully recover the airplane after the dive was stopped.

The results of the above analyses strongly suggest the possibility that some or the entire right elevator broke off some time shortly after the dive began. If that occurred, the information on right elevator position that was sent to the FDR is meaningless, and the argument that the recorded elevator split was due to a fight in the cockpit is simply wrong.

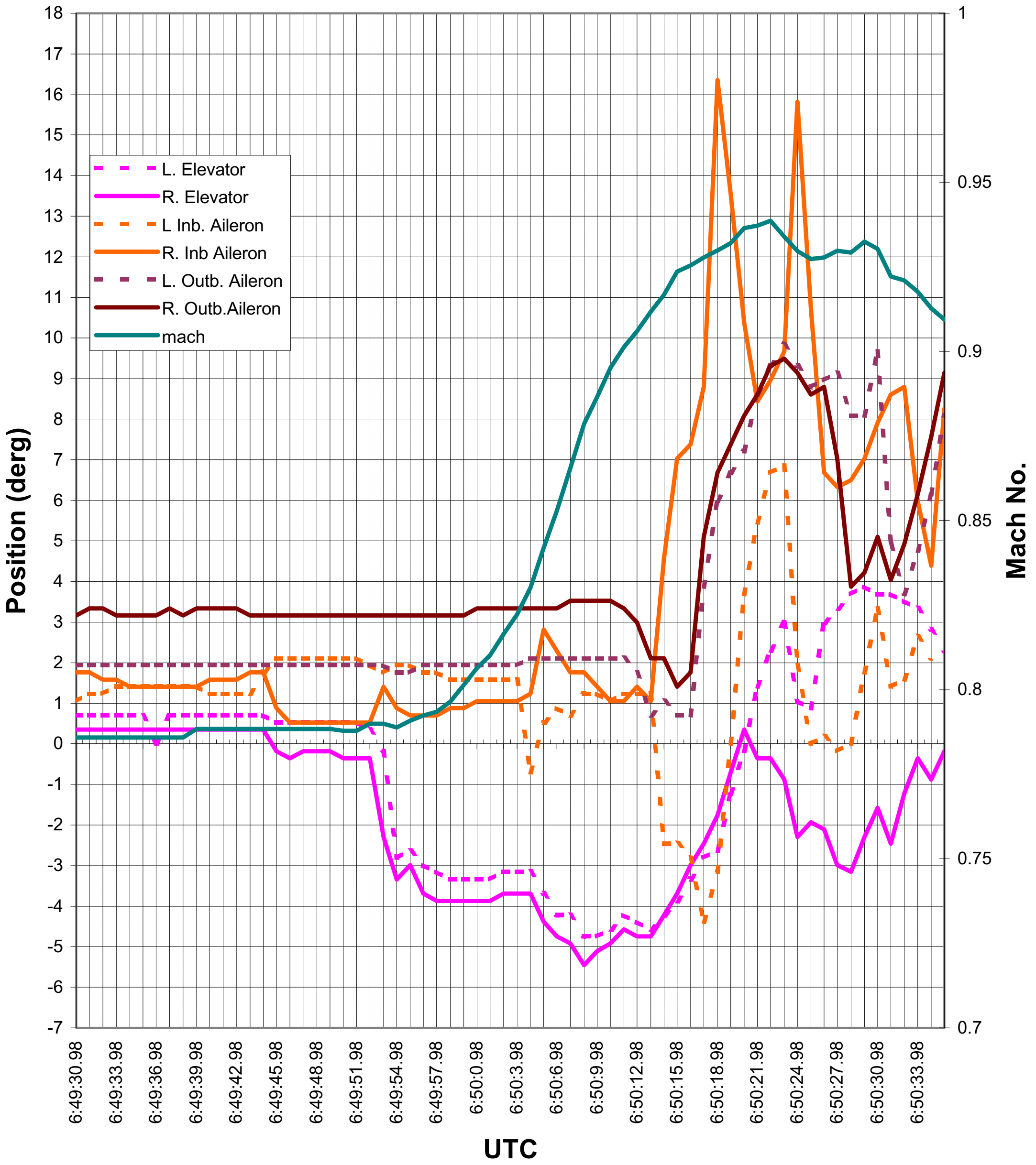

Figure A-2.1. FDR Elevator and Aileron Deflection and Derived Mach number

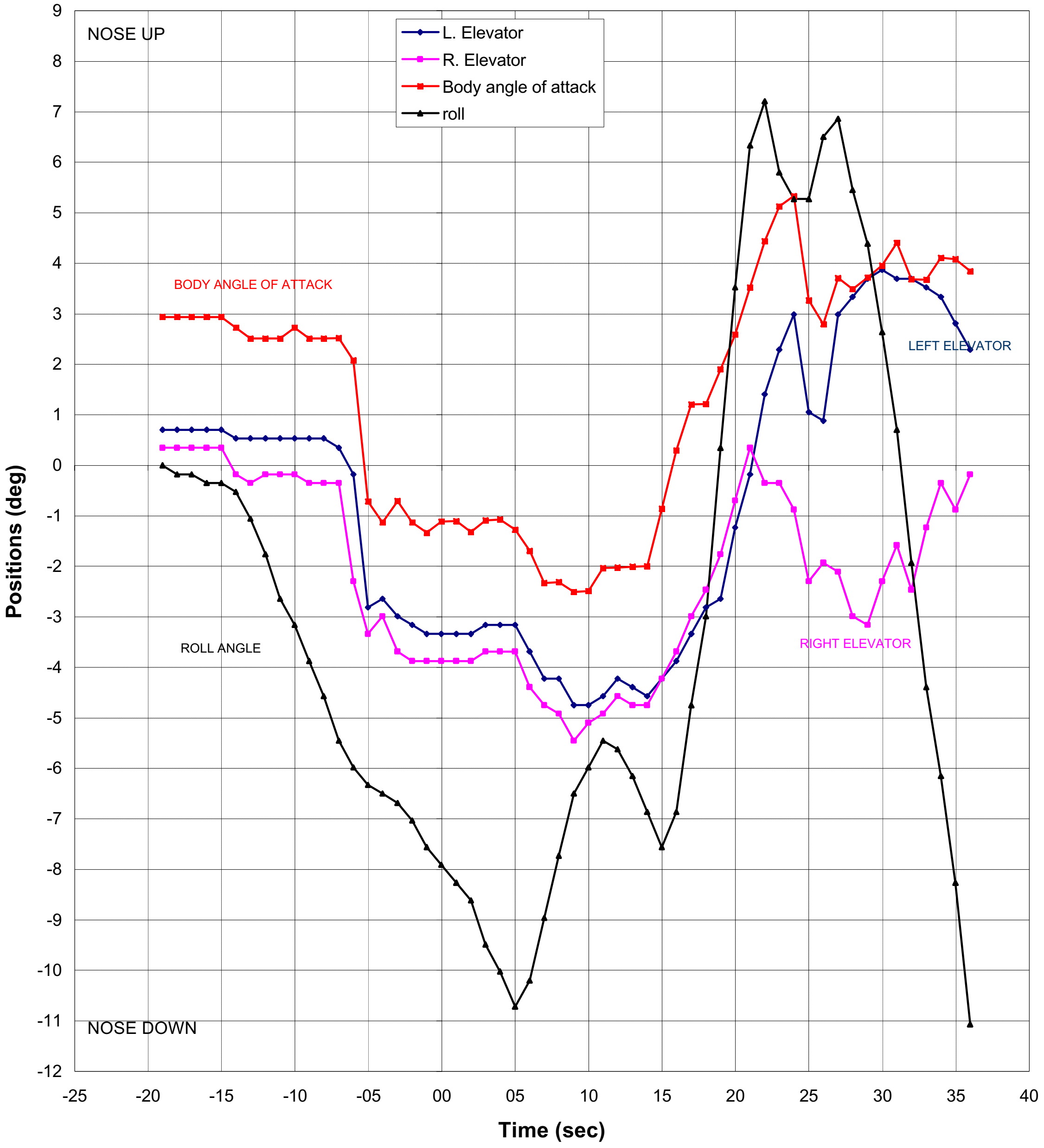

Figure A-2.2. FDR Roll Angle and Derived Body Angle of Attack

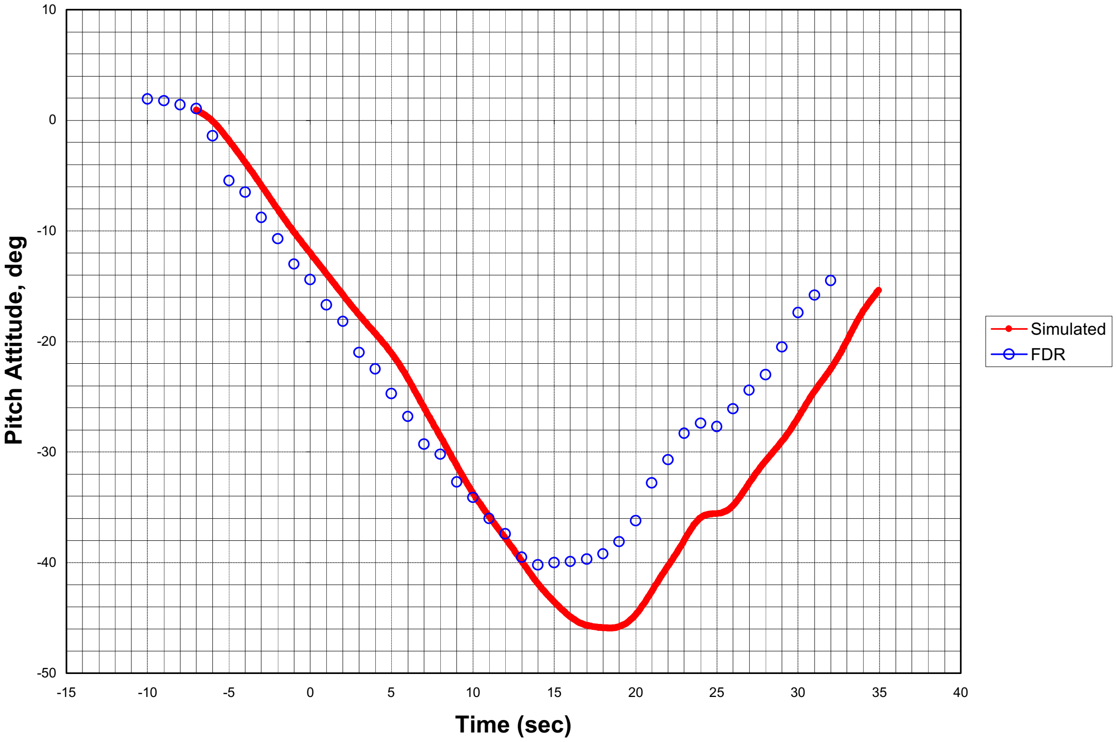

Figure A-2.3. . Pitchover Simulation, Right Elevator as Recorded on the FDR

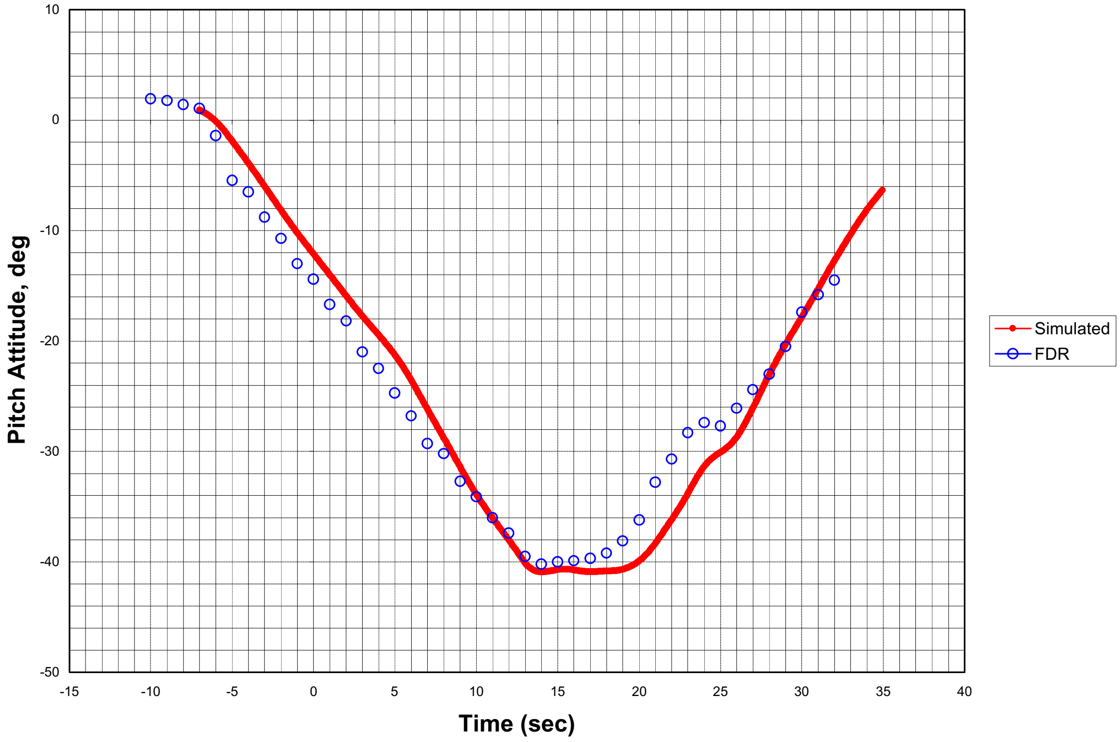

Figure A-2.4. Pitchover Simulation, Right Elevator Missing

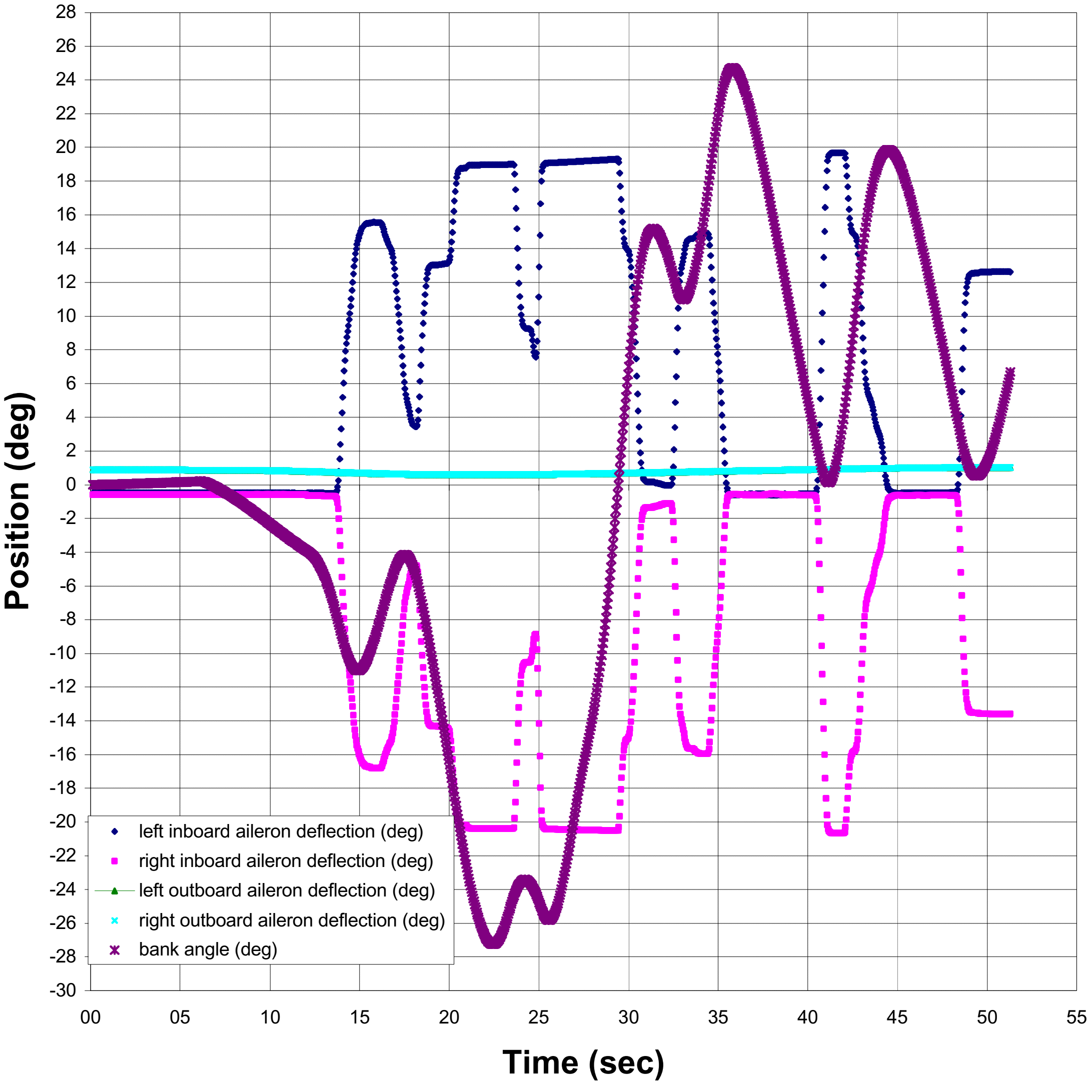

Figure A-2.5. Aileron Deflection and Bank Angle from Data Recorded at the Second E-Cab Simulation Session

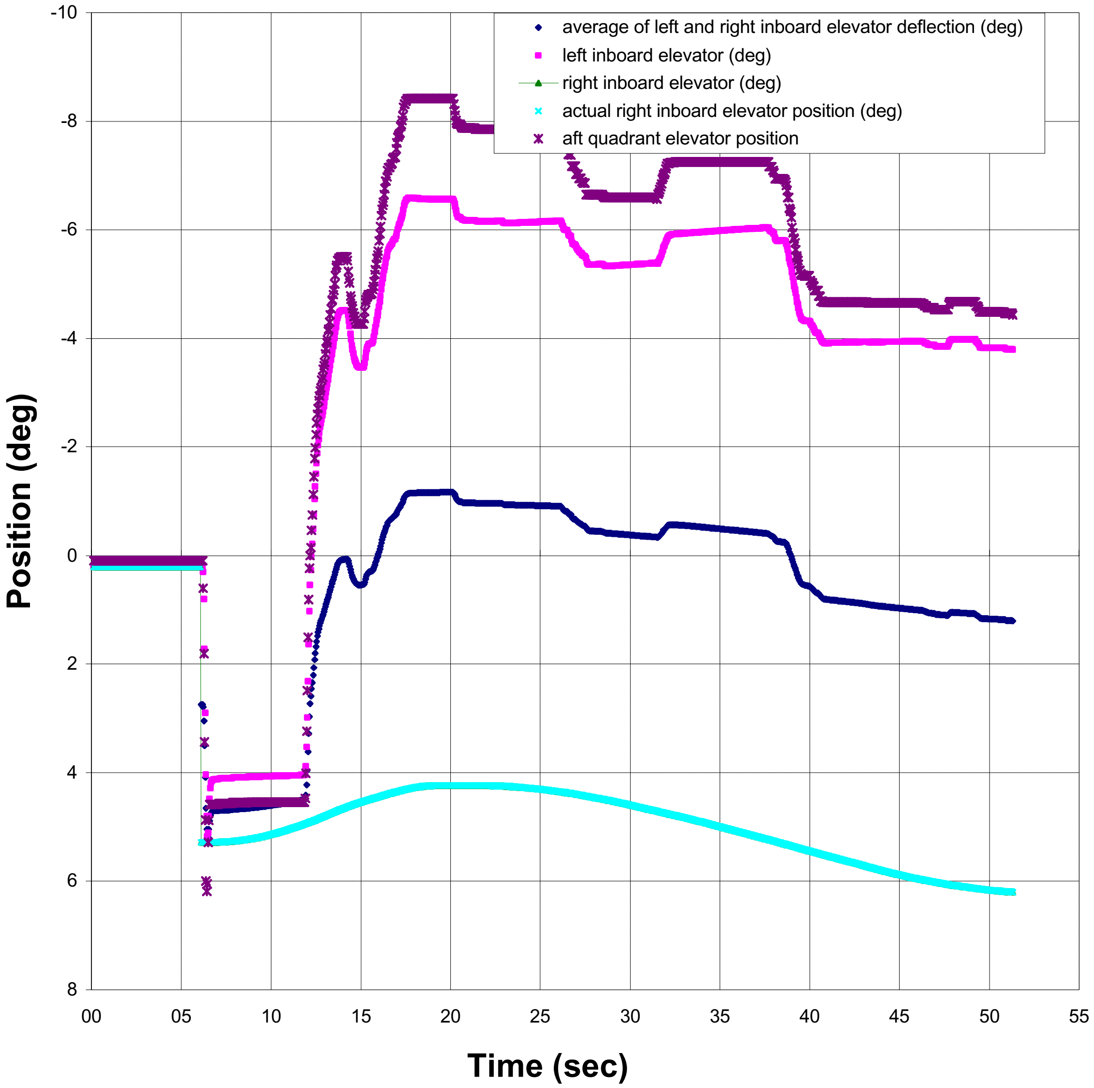

Figure A-2.6. Elevator Deflection from Data Recorded at the Second E-Cab Simulation Session

Appendix A-3

Detailed Analysis of Ground Test Data

Ground tests were conducted on a Boeing 767-400 with the intent of gaining an understanding of the effects of various elevator system malfunctions, and validating the Boeing analytic study.

Examination and analysis of ground test data revealed the following:

The ground tests results for the tests conducted on December 1999, for elevator sweep at normal condition (with elevator feel pressure 770 psi), did not show a close match with the charts presented by Boeing letter for evaluating the elevator failures conditions. Figure A-3.1 shows a comparison of the test results and an excerpt of the data provided by Boeing.[36]

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[36] Boeing Letter B-H200-16968-ASI-R2 (Split Elevator Failure Scenario, dated September 29, 2000) and Boeing report B-H200-17026-ASI, (767 Elevator System Operation with Regard to Column Splits, Aft Quadrant Splits, and Column Jams, dated August 2, 2000).

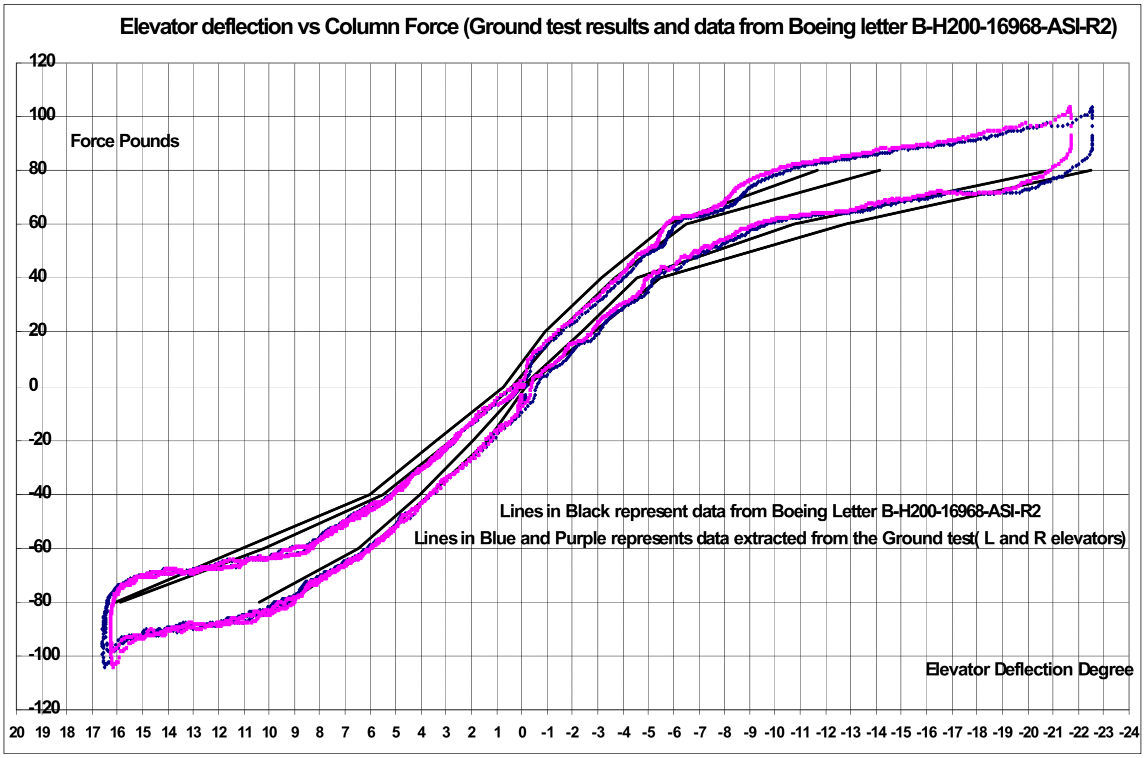

Figure A-3.1. Elevator Force-Deflection relationship (Ground test and Engineering data)

The ground test data revealed that when the column was not loaded by the pilot, there were non-zero column forces recorded. Boeing explained this discrepancy as due to temperature effects; however, no record of the temperature was maintained. In addition, no correlation between time of day and time since the last test could be established. Boeing arbitrarily chose to apply a different bias on each test in order to get zero force at the beginning of each test. This procedure is arbitrary and not based on any accepted scientific methodology.

Further, Boeing's explanation of force bias due to temperature effects is not supported by the data. Figure A-3.2 shows the bias on the Captain's column force measurement increasing with time, with the suggestion that changes in temperature caused this change in bias. If temperature were the cause of the change in bias, the bias in the First Officer's force measurement would have increased as well, but instead, it decreased. In addition, the bias on the First Officer's force measurement does not change in the nearly linear manner that the bias on the Captain's force measurement does. If both force transducers have the same specifications, they should react to temperature in a very similar manner; there should not be an opposite reaction to changes in temperature.

Figure A-3.3 shows the bias during another test, but this time, the bias on the First Officer's force measurement increases much more rapidly than in the earlier test. This suggests that the temperature effects on the transducers are random because the temperature dependence more than triples between tests. Even if the temperatures had been recorded during the tests, that information would not have been useful for calibrating the force measurement because of the apparently varying temperature coefficients.

The explanation that some of the bias is due to forces being applied prior to the start of the test is also flawed. If that were the case, there would be no logical way to apply a bias correction based on the value of the force at the start of the test. Each bias value depends on the amount of force being applied by the pilot at the precise time the test is started.

Even with the use of the Boeing methodology to correct the measured forces in the ground test, the forces induced as a result of PCA failures from the 767 ground test were significantly higher than the Boeing prediction in its analytical study for the induced force. Therefore, any conclusion should be based on the actual forces as shown during the ground test and not on Boeing's prediction.

Only the forces applied to the control column by the Captain and the First Officer were measured. Boeing failed to account for any induced force back driving the elevator control system as a result of the failure scenario being studied. Consequently, there is no accurate analysis of the actual control forces that the Flight 990 crew faced.

The ground tests often produced results that differed either from the E-Cab data or from results predicted by Boeing. For example, during the ground tests on a 767, it was found that a given column force results in a wide range of elevator deflections at the same specific condition and elevator feel pressure. Boeing used induced column force to determine elevator position; however, their ground tests showed that there is a band of elevator positions associated with any given force. Boeing in its analytical studied, associated each value of column force with a unique elevator position, disregarding the test results showing that there is a band of possible elevator positions associated with a column force. See Figures A-3.4 to A-3.11.[37] The band of possible values of elevator position, should not be ignored when reaching any conclusion.

In most cases of ground test, there was a difference of about 2 degrees between both elevator surfaces, however, both the left and right columns showed the same positions. This is not consistent with Boeing's analytical study described in Boeing letter B-H200-16968-ASI-R2, dated 29 Sep 2000.

Also, in its letter B-H200-17027-ASI, dated 4 August 2000, Boeing stated that the actual magnitude of the elevator surfaces deflection is influenced by several factors. These factors include:

- The stiffness of the elevator surface deflection.
- The location of the elevator position sensor.
- The PCA chosen to insert the fault.

Although Boeing's explanation is valid, Boeing did not use this approach in its analysis for dual failure (Boeing report B-H200-16968-ASI-R2 -Split Elevator Failure Scenario, dated September 29, 2000). Also Boeing did not include these factors in its simulation model during the E-Cab test. Boeing corrected its approach only to show that the ground test data was valid, but did not use that correction consistently. Boeing should have applied the correction in all cases where elevator position was predicted.

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[37] Compare with Boeing Figures 49, 50, 51, 52, 57, 59, 61, 62 attached in Appendix D of the Systems Group Chairman's Factual Report Addendum Regarding the Ground and Simulation Testing dated July 26, 2000.

In its report B-H200-16968-ASI-R2 (Split Elevator Failure Scenario, dated September 29, 2000), Boeing predicted that there would be no split in the normal deflection of the elevators if a single PCA jam had occurred. The ground testing of an exemplar 767 showed, however, that differential displacement of the elevators did occur. Figures A-3.12 and A-3.13 were derived from data collected by Boeing during the ground testing and show that there is a difference in the deflections of the right and left elevators during a single jam failure, contrary to what was predicted by Boeing. This difference is about 0.7 degrees. This elevator behavior is precisely what was recorded on the FDR after the autopilot was disconnected and before the dive began. Further, the Boeing analysis predicted that the induced force at zero displacement would be approximately 15 pounds. The testing showed that the measured force was between 30 and 45 pounds. This demonstrates the problem with using force as the independent variable in any analysis.

The data gathered during the ground tests conducted on the 767 does not support the Boeing mathematical study regarding single and dual PCA failures. In addition, the data does not correspond with the mathematical description of the elevator control system previously provided by Boeing. See Figures A-3.14 to A-3.17. These Figures present the elevators deflection as obtained from Boeing analytical model and the 767 ground test.

As shown in these figures, the “elevator force – deflection relationship” obtained from the 767 ground test is not consistent with the relationship obtained analytically in Boeing report B-H200-16968-ASI-R2 (Split Elevator Failure Scenario, dated September 29, 2000) and Boeing report B-H200-17026-ASI, (767 Elevator System Operation with Regard to Column Splits, Aft Quadrant Splits, and Column Jams, dated August 2, 2000).

The actual ground test results always show much higher force at the same elevator deflection compared with Boeing analytical results on which Boeing based most of its conclusions.

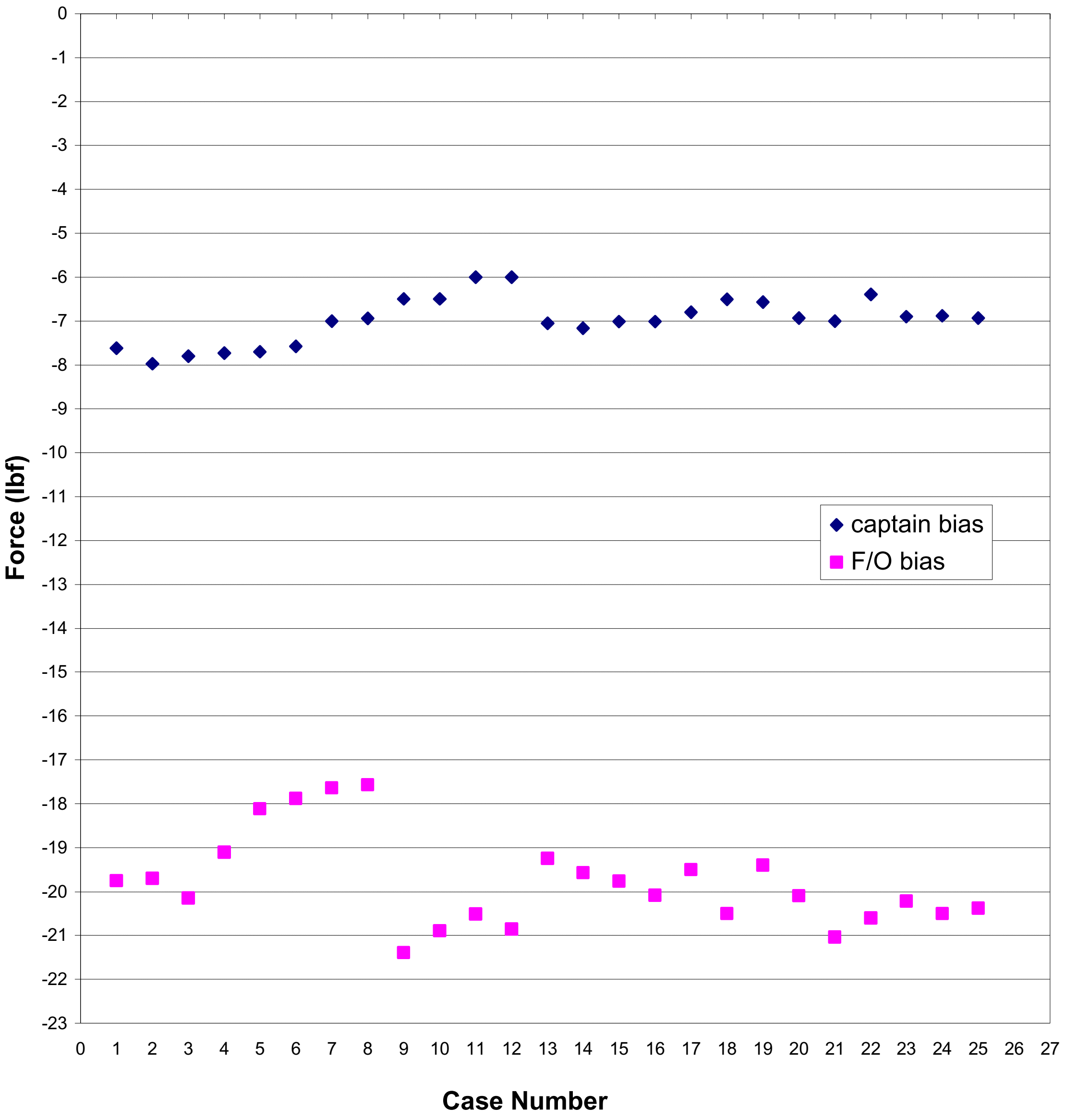

Figure A-3.2. March Ground Test Data, Bias Changes for Captain and First Officer Column Force Measurements

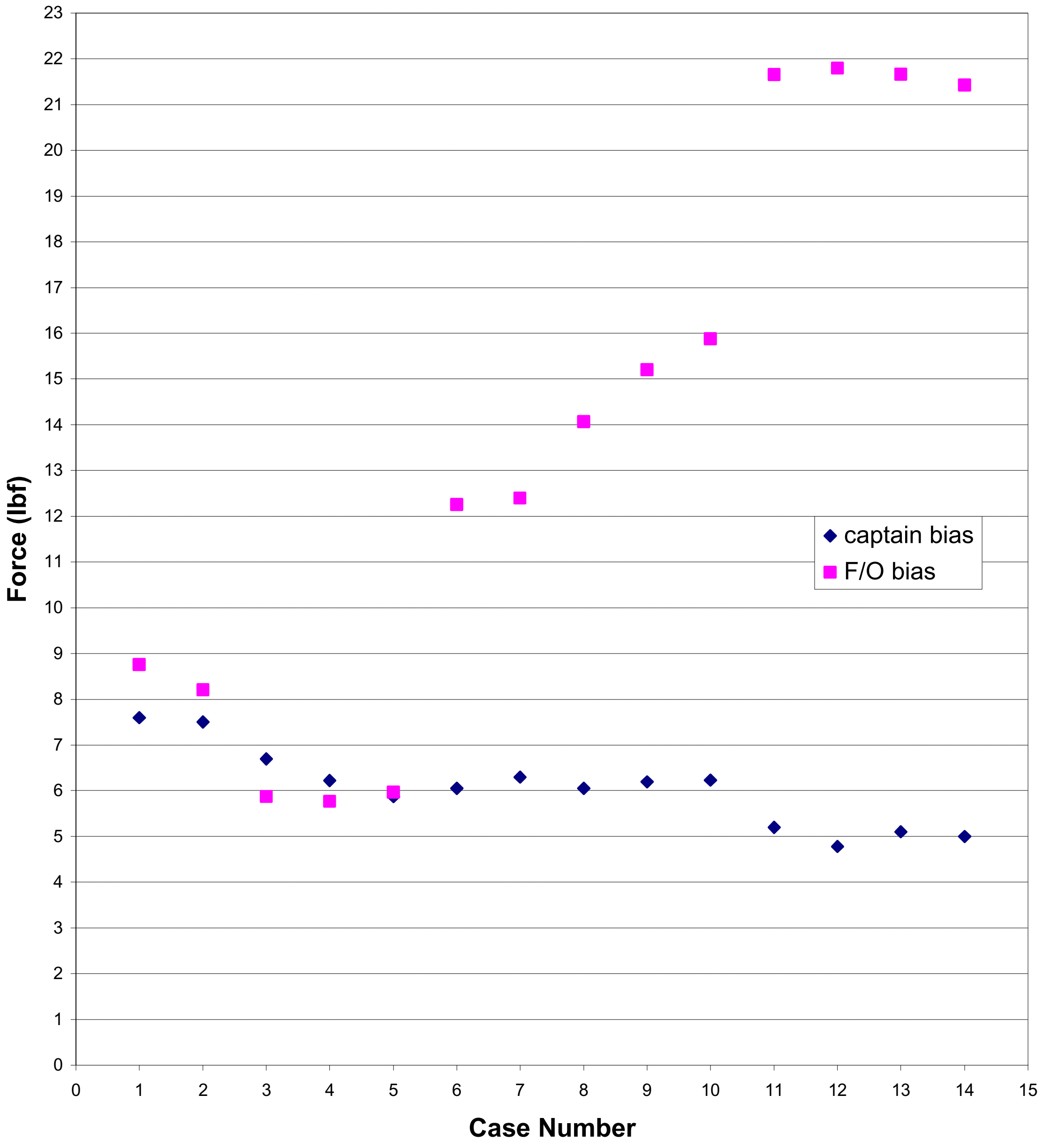

Figure A-3.3. April Ground Test Data, Bias Changes for Captain and First Officer Column Force Measurements

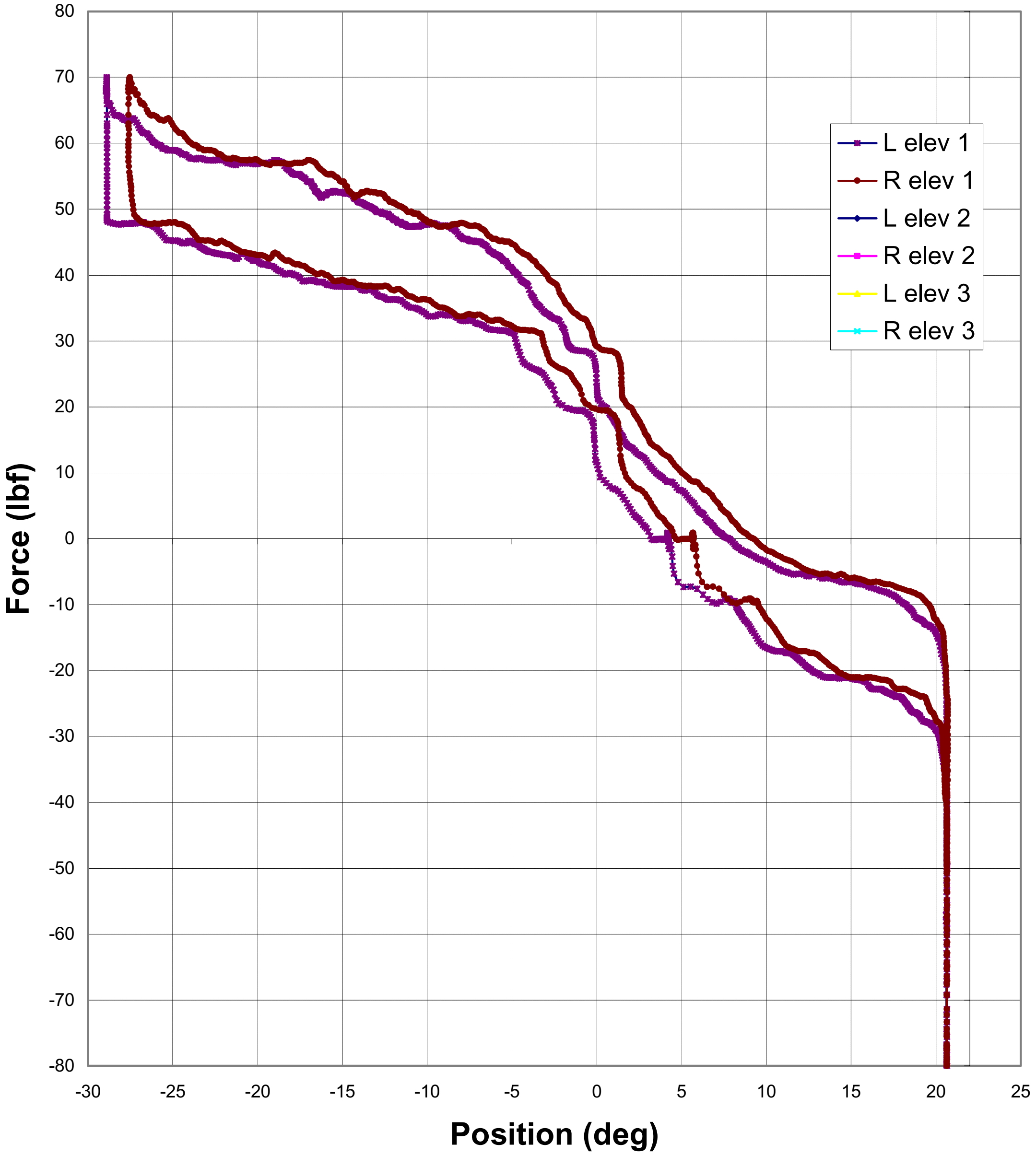

Figure A-3.4. B-767 Ground Test Data, Single PCA Jam, Base Elevator Feel Pressure, First Officer Column Sweep

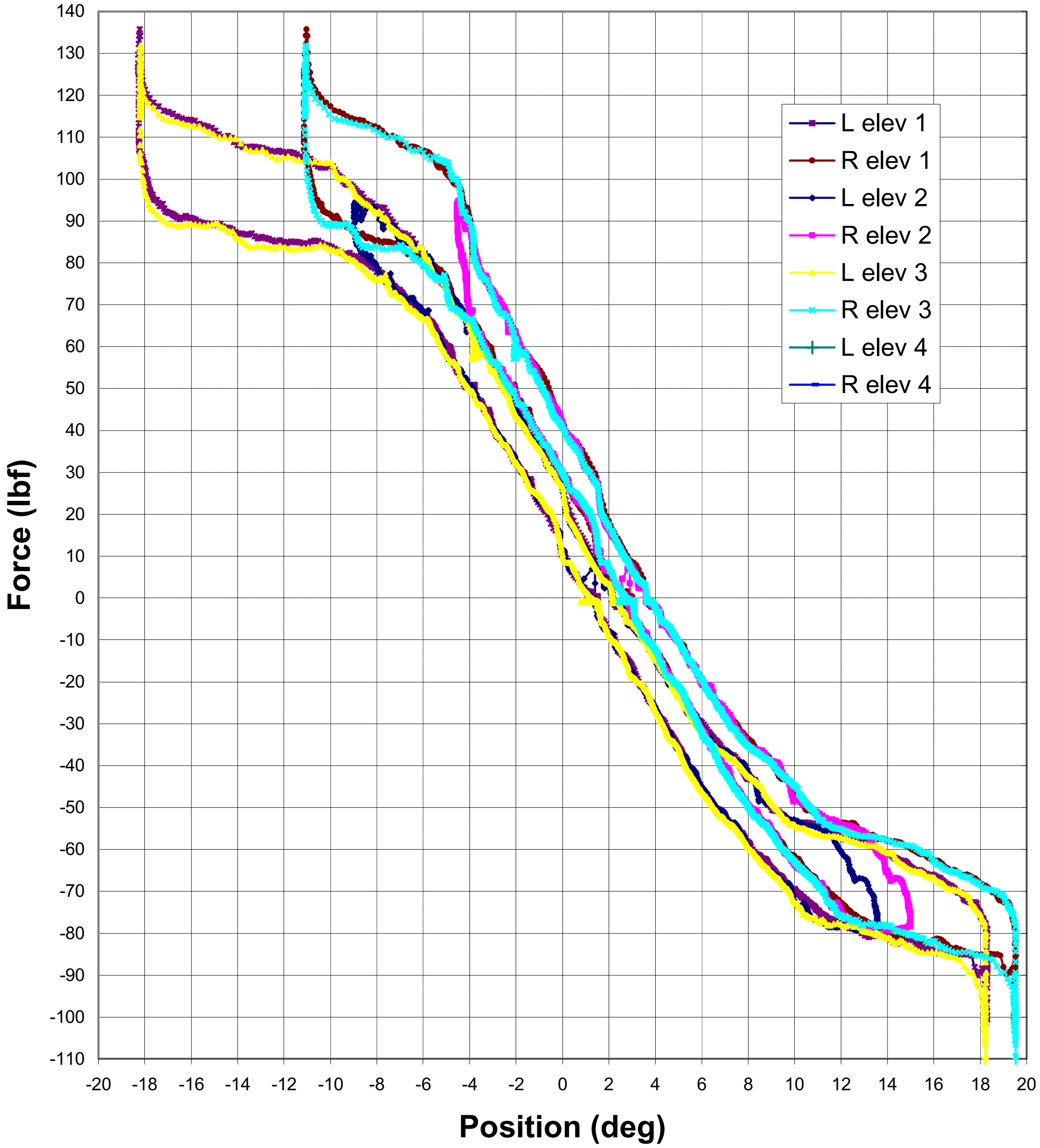

Figure A-3.5. B-767 Ground Test Data, Single PCA Jam, 770 psi Elevator Feel Pressure, Pilot Column Sweep

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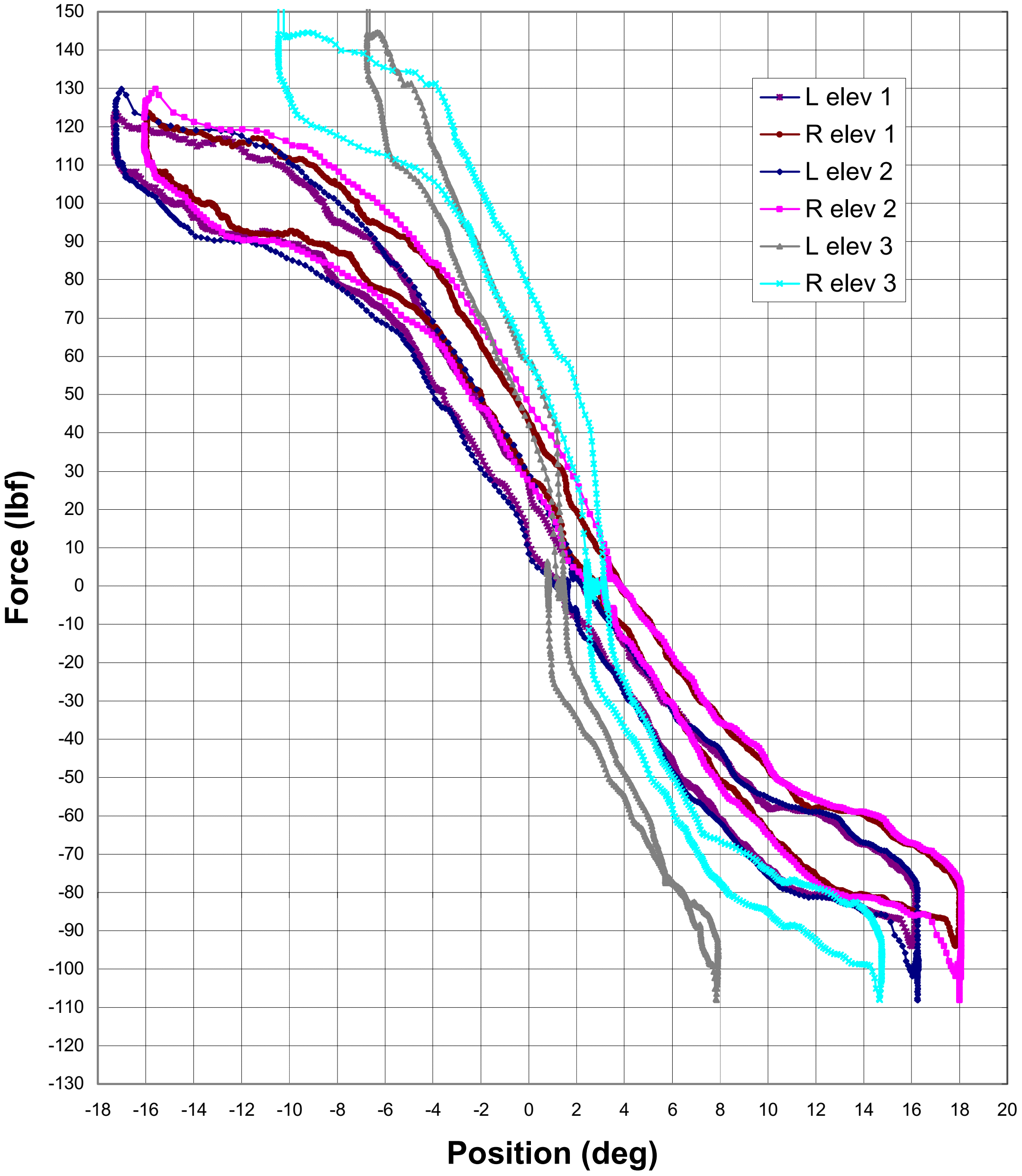


Figure A-3.6. B-767 Ground Test Data, Single PCA Jam, 770 psi Elevator Feel Pressure, First Officer Column Sweep

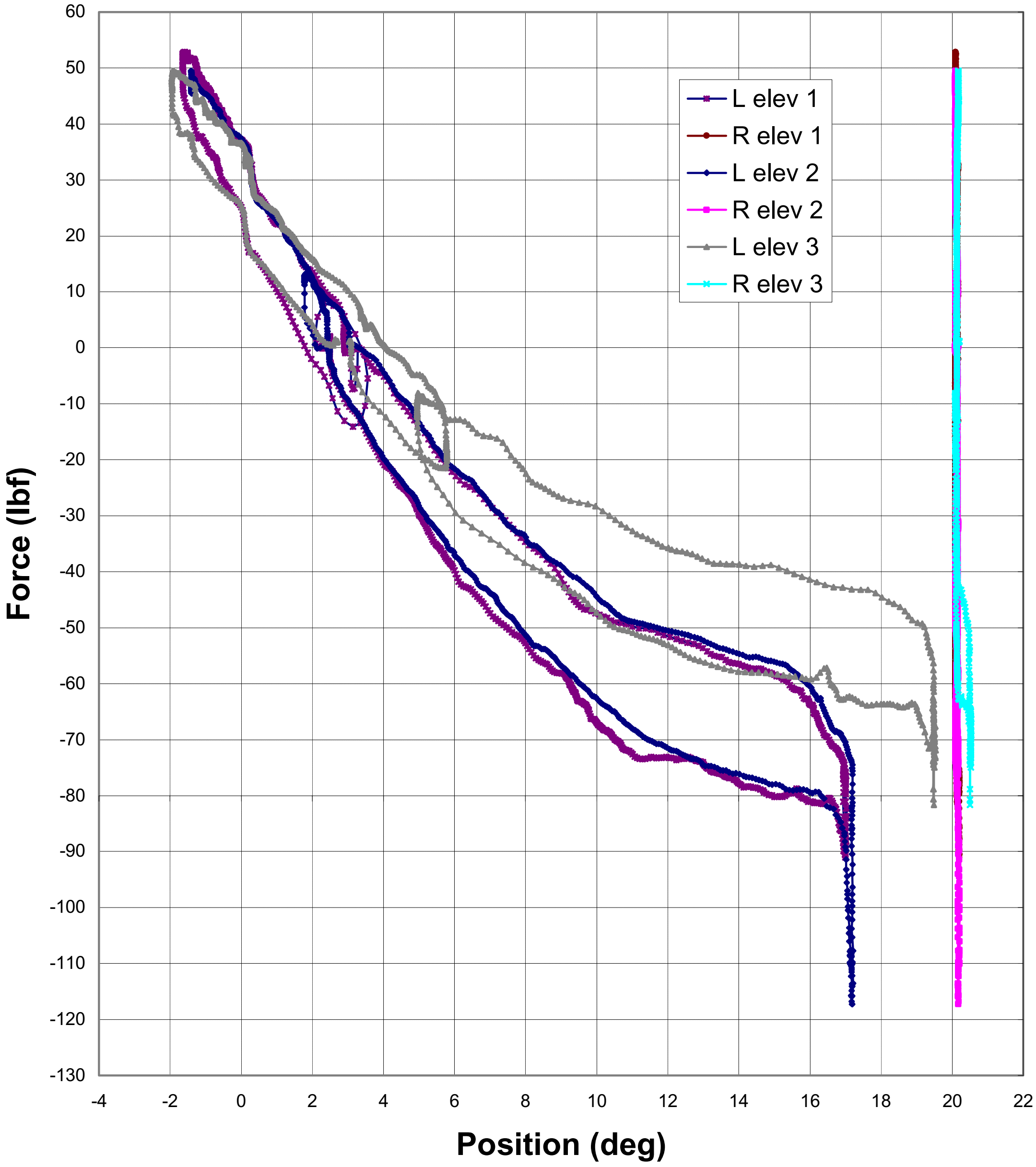


Figure A-3.7. B-767 Ground Test Data, Single PCA Jam and One PCA Disconnected, 770 psi Elevator Feel Pressure, First Officer Column Sweep.

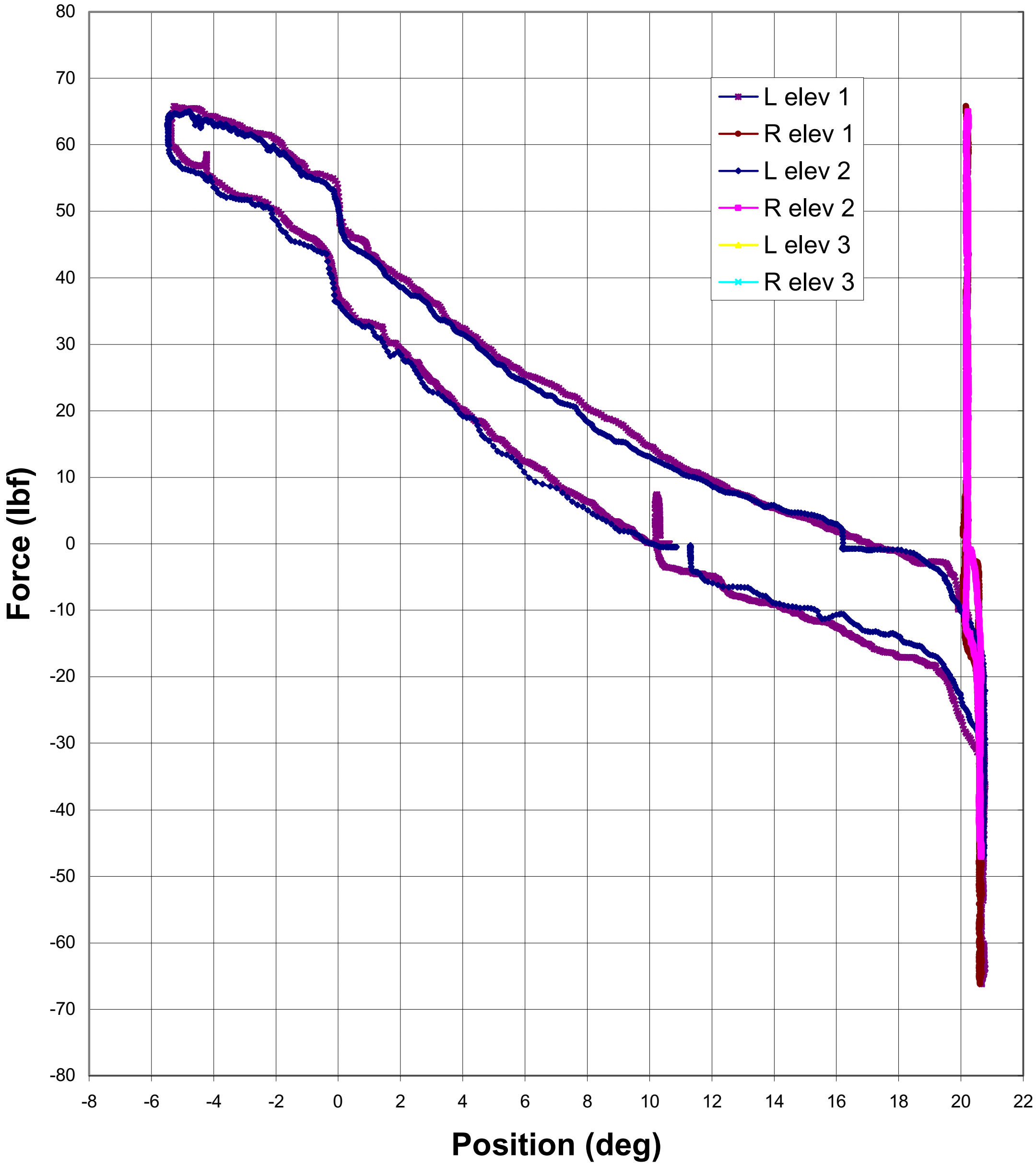


Figure A-3.8. B-767 Ground Test Data, Dual PCA Jam, Base Elevator Feel Pressure, Pilot Column Sweep.

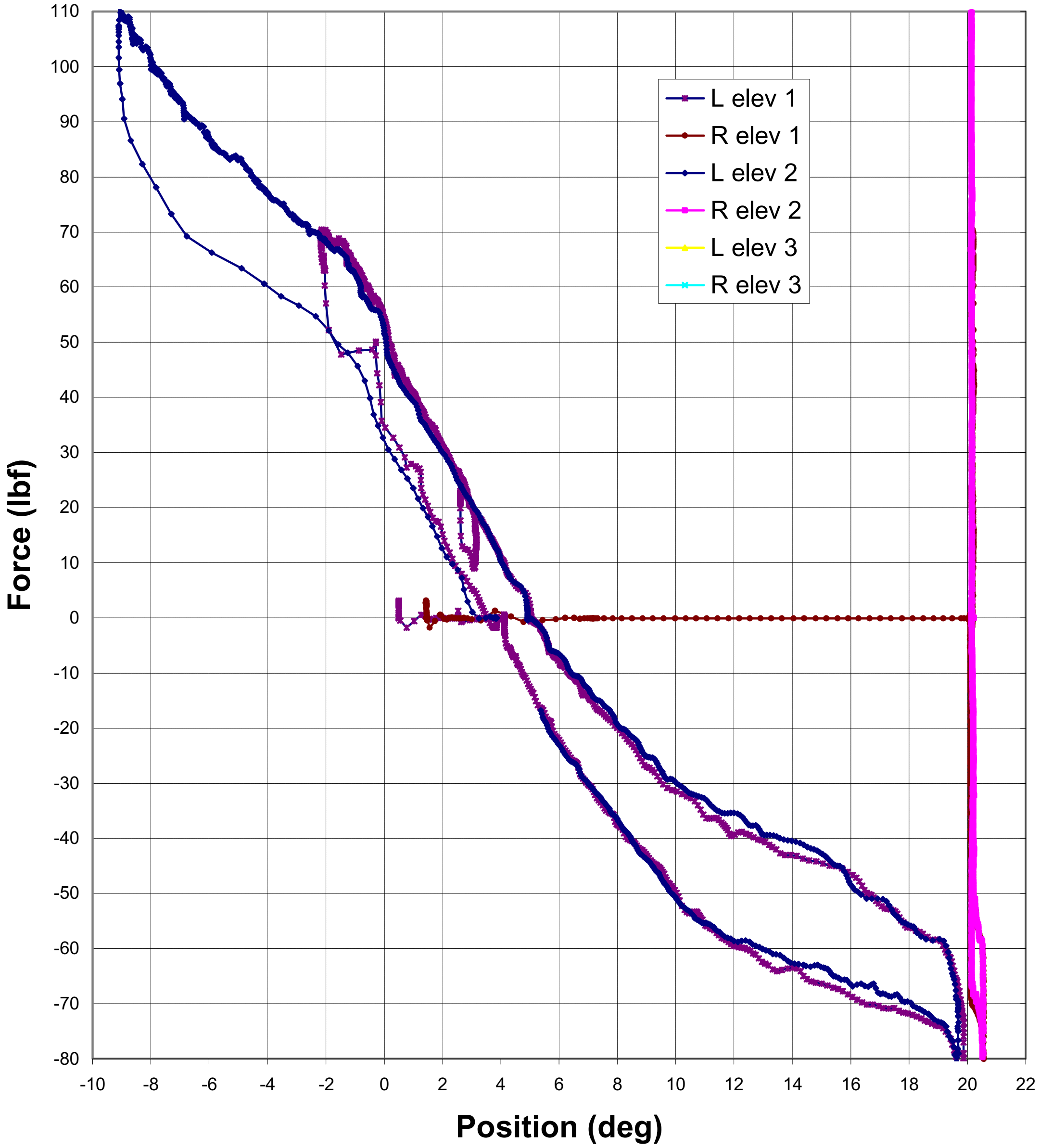


Figure A-3.9. B-767 Ground Test Data, Dual PCA Jam, 770 psi Elevator Feel Pressure, Pilot Column Sweep

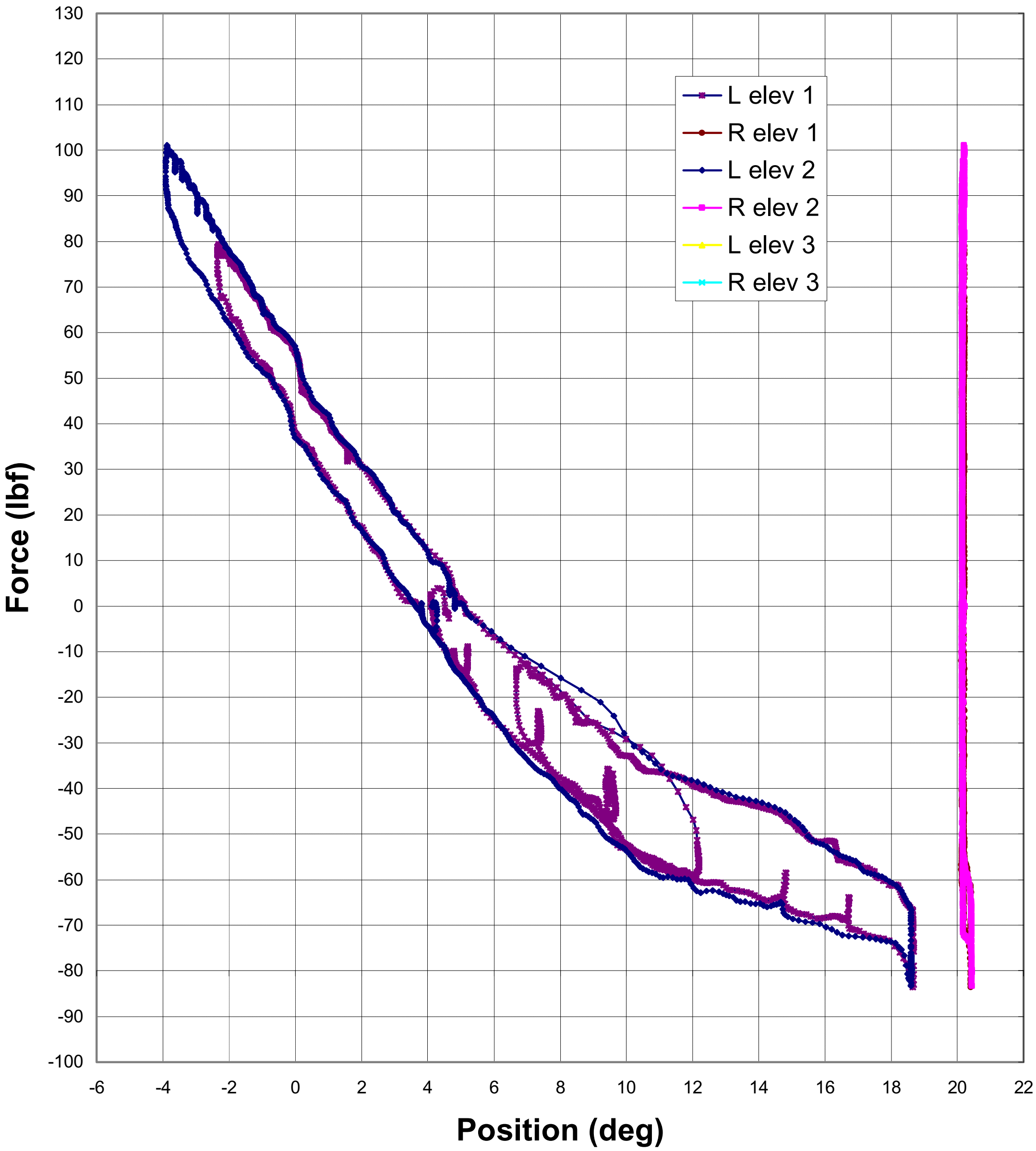


Figure A-3.10. B-767 Ground Test Data, Dual PCA Jam, 770 psi Elevator Feel Pressure, First Officer Column Sweep

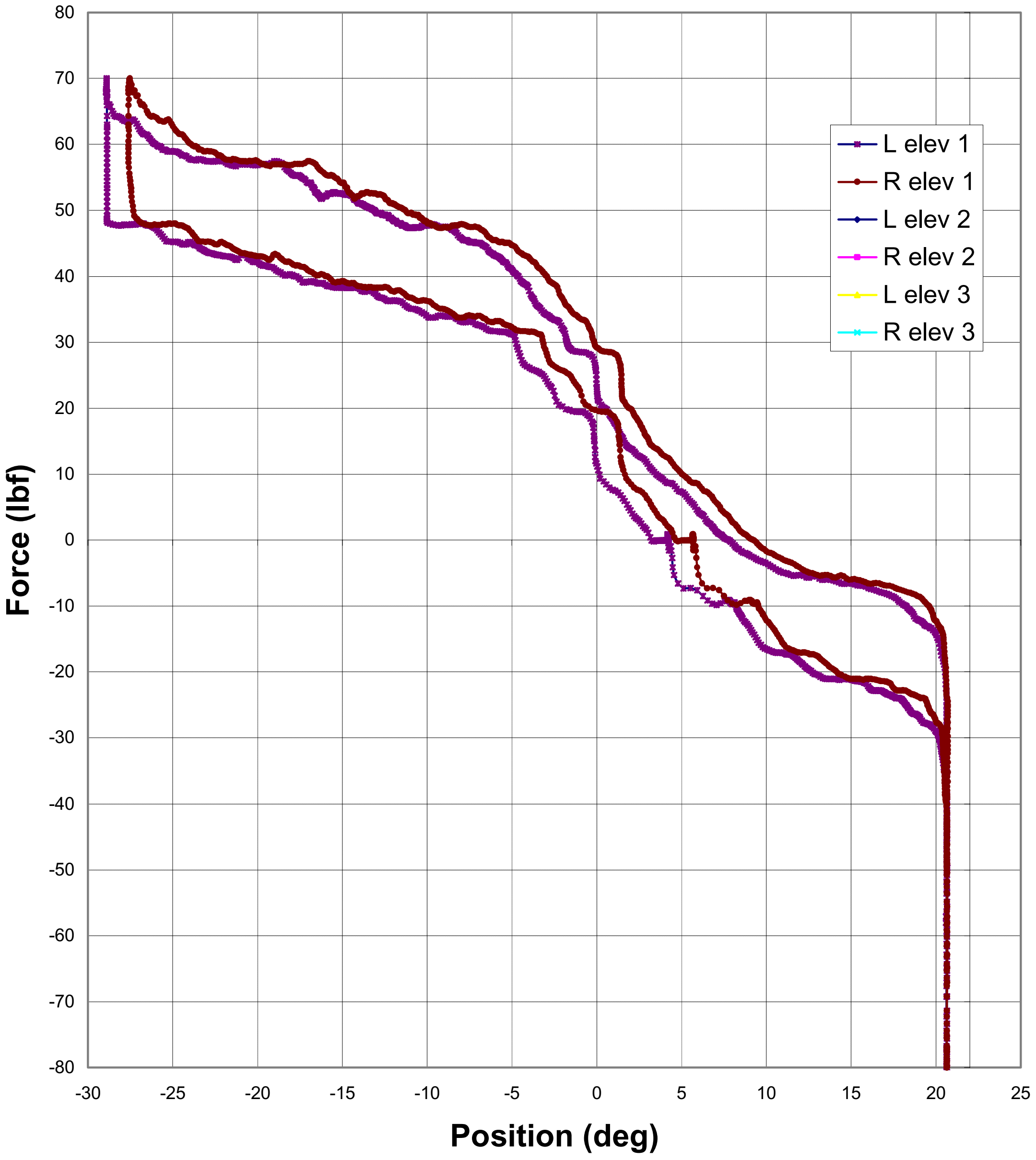


Figure A-3.11. B-767 Ground Test Data, Dual PCA Jam, 770 psi Elevator Feel Pressure, First Officer Column Sweep

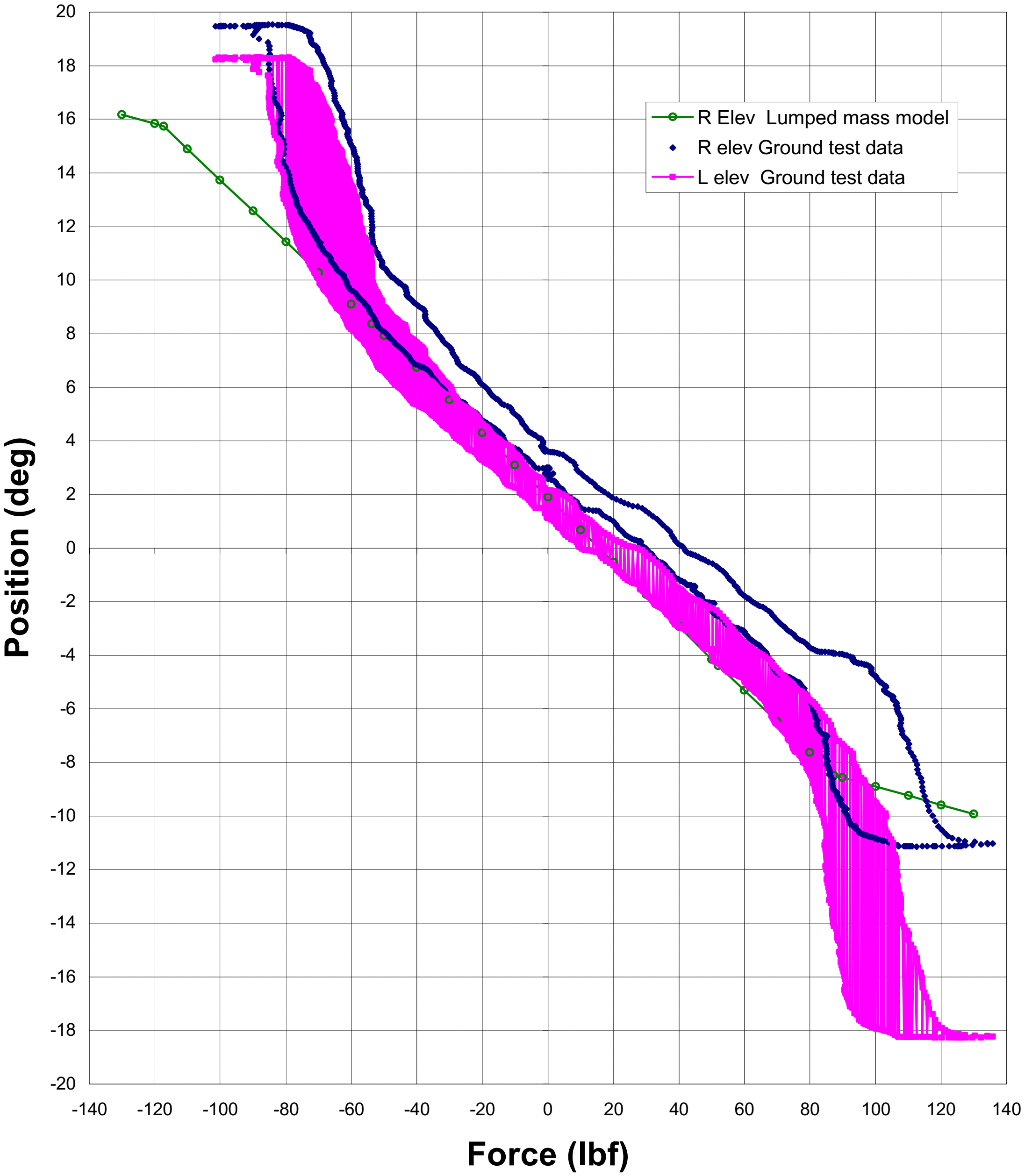


Figure A-3.12. B-767 Ground Test Results Extracted from Boeing CD Compared to Boeing Mathematical Lumped Mass Elevator Model, Single PCA Jam, Condition A

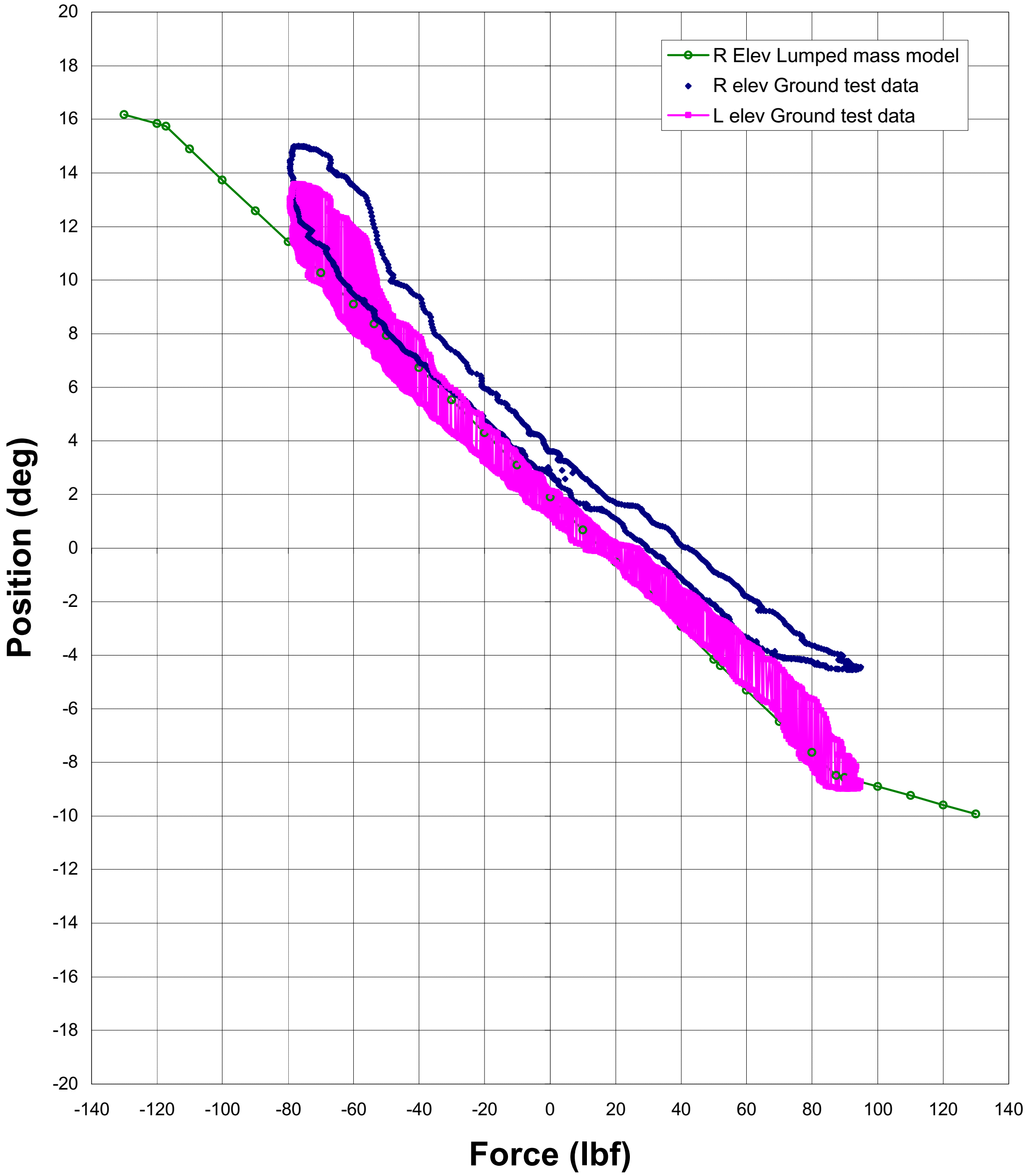


Figure A-3.13. B-767 Ground Test Results Extracted from Boeing CD Compared to Boeing Mathematical Lumped Mass Elevator Model, Single PCA Jam, Condition B

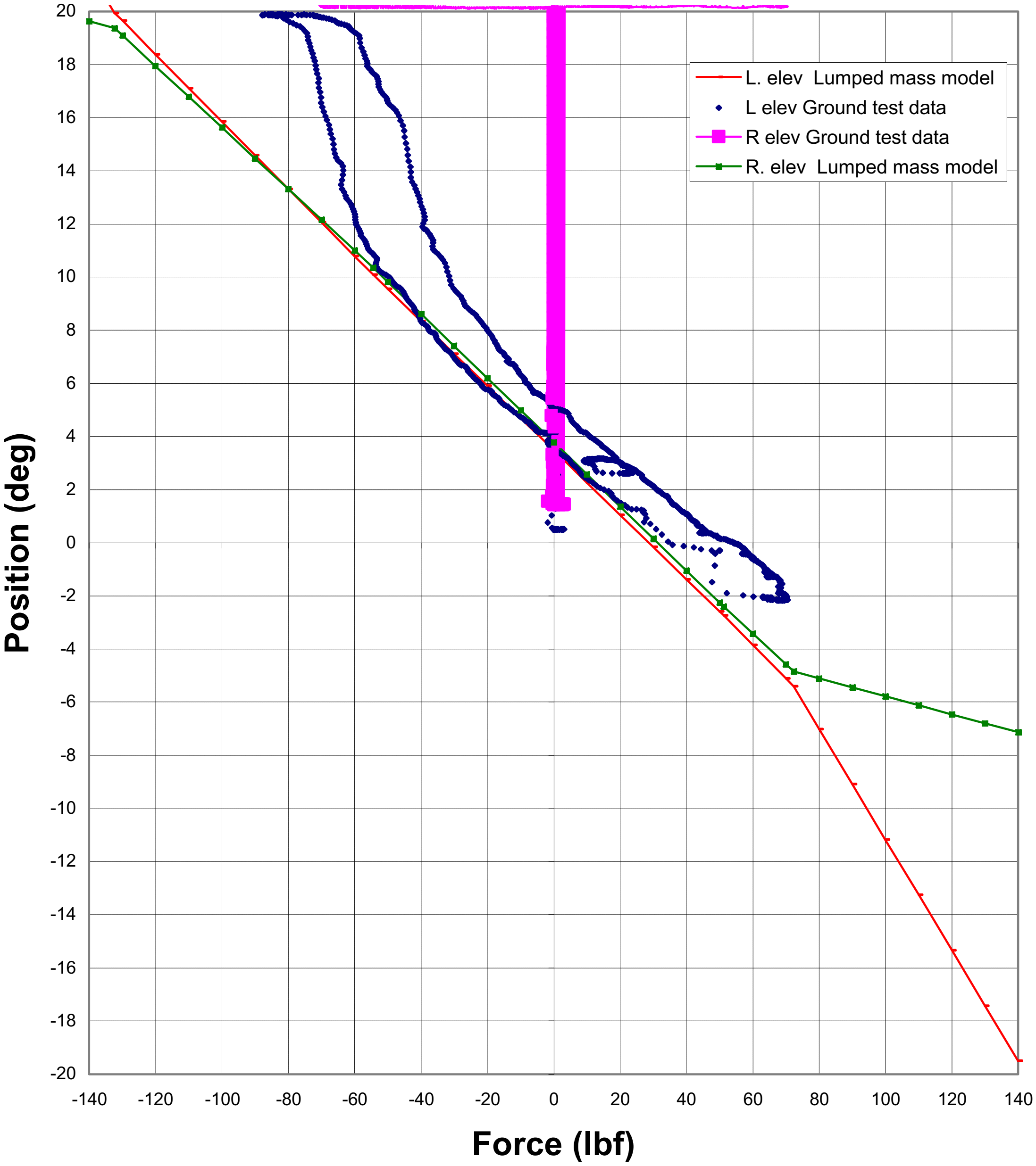


Figure A-3.14. B-767 Ground Test Results Extracted from Boeing CD Compared to Boeing Mathematical Lumped Mass Elevator Model, Dual PCA Jam, 770 psi Feel Pressure, Pilot Control Sweep, Condition A

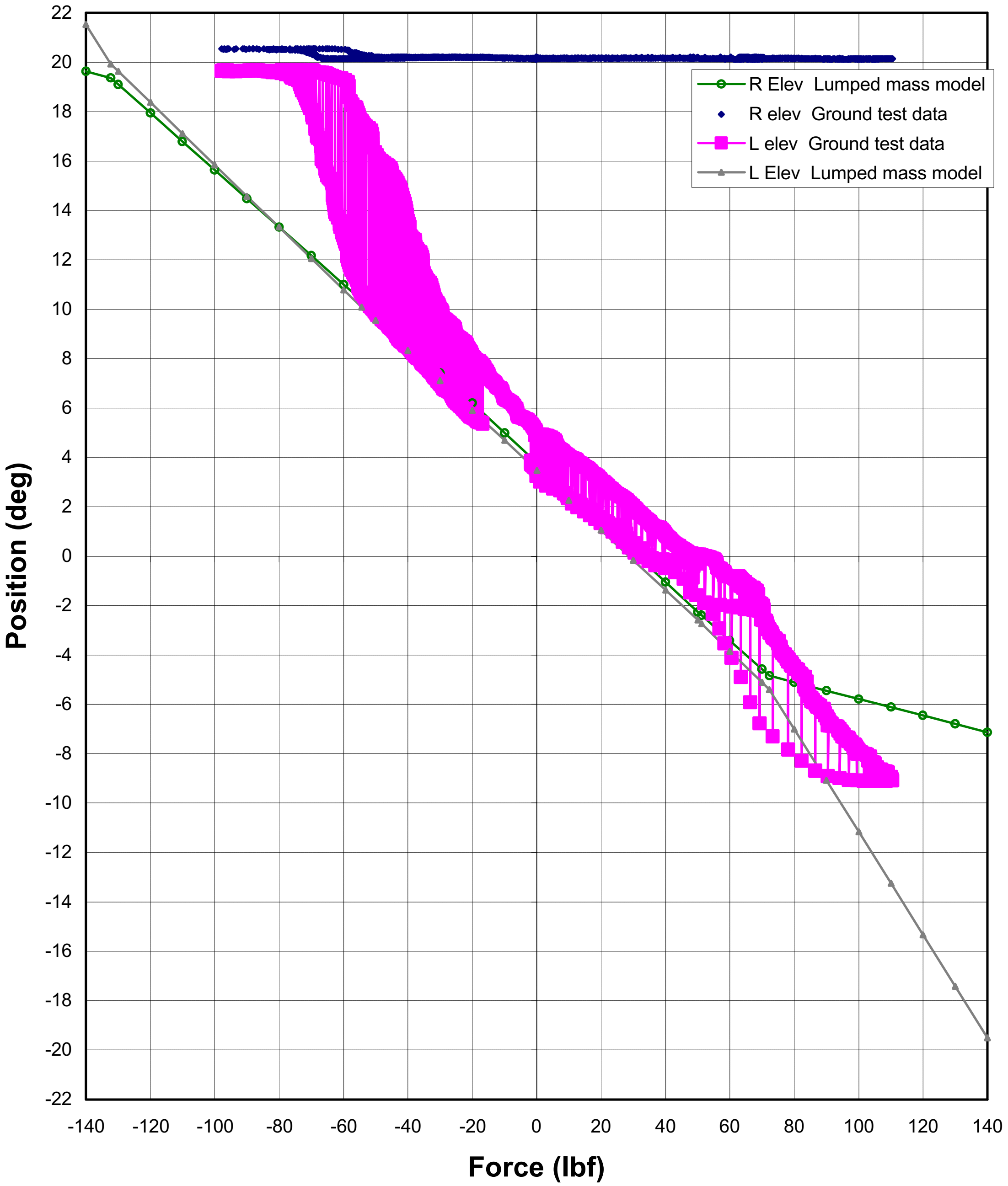


Figure A-3.15. B-767 Ground Test Results Extracted from Boeing CD Compared to Boeing Mathematical Lumped Mass Elevator Model, Dual PCA Jam, 770 psi Feel Pressure, Pilot Control Sweep, Condition B

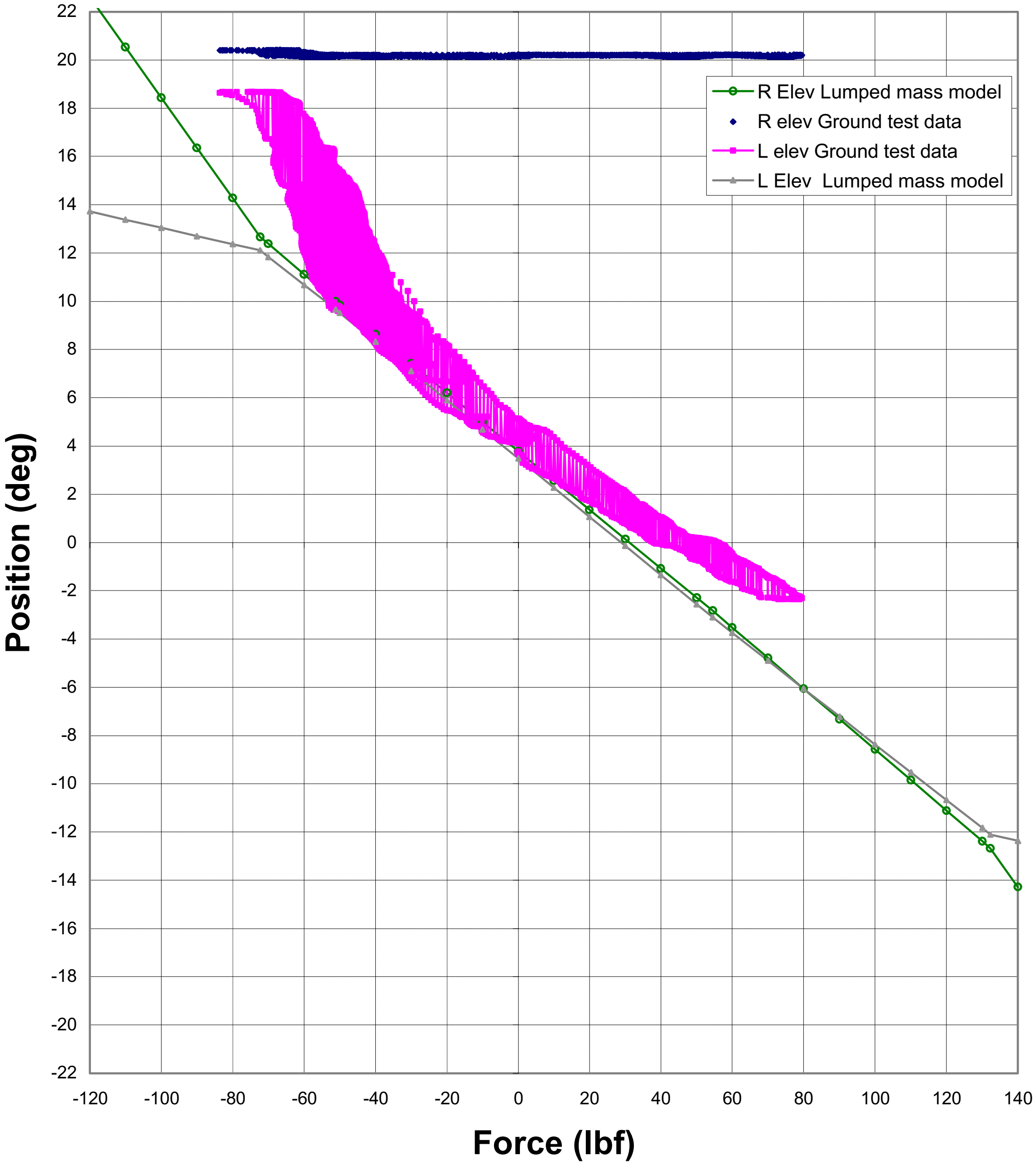


Figure A-3.16. B-767 Ground Test Results Extracted from Boeing CD Compared to Boeing Mathematical Lumped Mass Elevator Model, Dual PCA Jam, 770 psi Feel Pressure, First Officer Control Sweep, Condition A

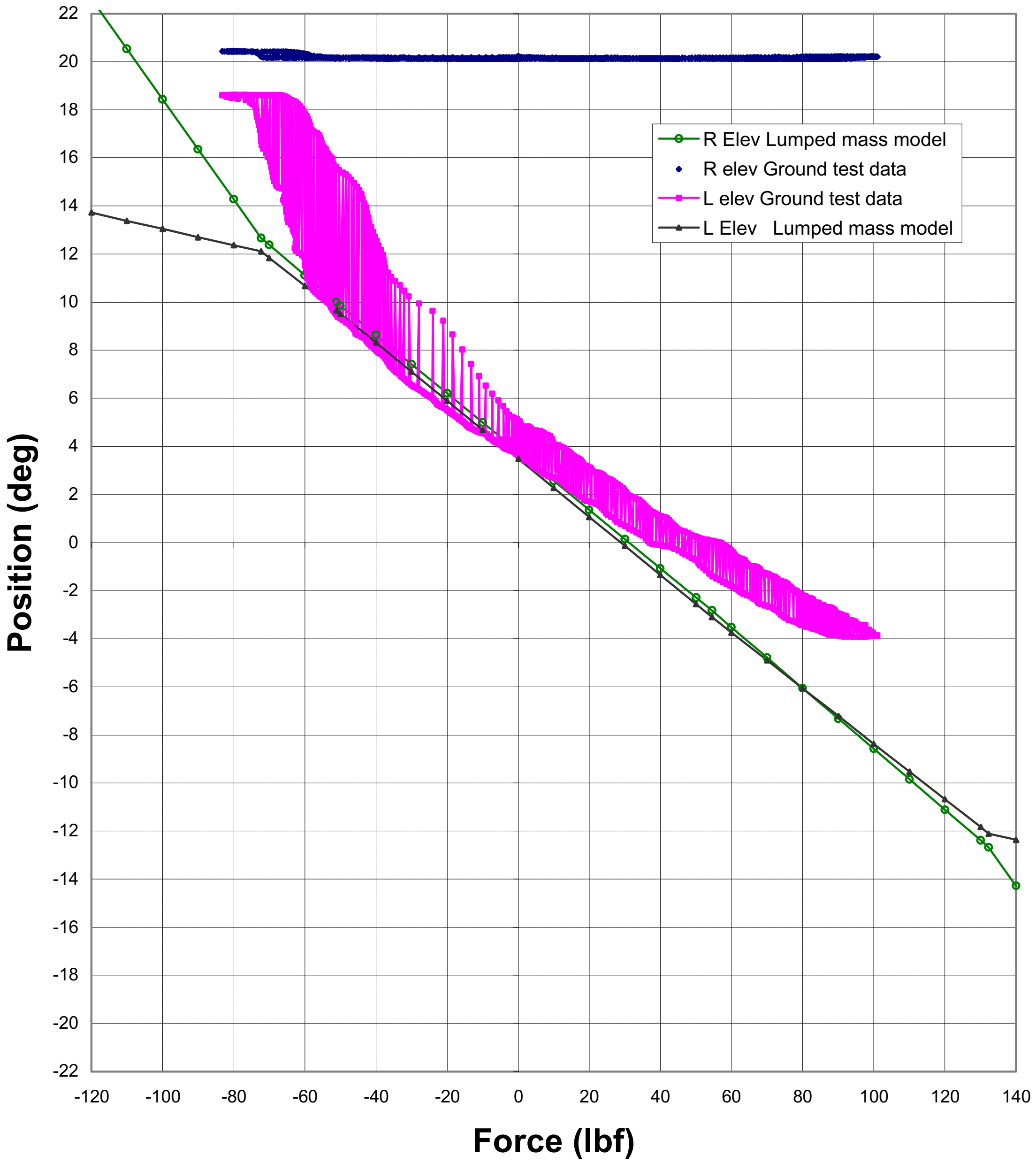


Figure A-3.17. B-767 Ground Test Results Extracted from Boeing CD Compared to Boeing Mathematical Lumped Mass Elevator Model, Dual PCA Jam, 770 psi Feel Pressure, First Officer Control Sweep, Condition B

Appendix A-4
Detailed Analytical Study on the Anomalies Found in One of the Recovered Elevator PCA's

The right outboard elevator PCA and servo were recovered. The manifold housing containing the servo valve was found attached to the PCA by the input arm. The bolts that connected the manifold housing to the PCA had been sheared. Examination of the servo revealed that the pin holding the spring guide to the slide had been sheared and the spring had looped over the spring guide

Boeing reported on an analysis of the forces required to shear the spring guide pins in their reports B-H200-17066-ASI and B-H200-17082-ASI. The acceleration needed to shear the pins in the spring guide is based on a double shearing force of 300 pounds. Based on the mass of the spring guide, a load of 19,551 "g" is needed to shear the pin if only inertial forces are considered. This is consistent with the Boeing analysis. Boeing calculated the acceleration needed to get the slide and guide up to 57.25 mph. This was done correctly, but this calculation only determines the acceleration needed to get to this speed, not the acceleration needed to create sufficient force to shear the pin. To fail the pins in the guide, the slide must be decelerated from 57.25 mph to zero speed at a rate of 19,551 "g." To put this value in perspective, flight data recorders are designed to withstand 4000 "g" in an impact.

To achieve an acceleration on the spring guide, the combined slide/spring/spring guide unit must be decelerated. The pin will then be loaded in shear during the deceleration. Boeing reported the mass of the slide as 47.5 grams (0.105 lbm). The force required to stop the slide alone is 2053 lbf (= 19,551 g * .105 lb). If the slide hit the end cap or the overtravel cam with this much force, a significant witness mark would have been produced. None was observed. The Boeing analysis reported that the loading required to shear the manifold-to-actuator bolts was 1843 “g.” The maximum loading that was applied to the servo was less than 10 percent (1843/19,551) of the load required to fail the pins in the spring guide. Once these bolts are sheared, the servo is no longer restrained and will be at zero “g” until it hits something else.

The energy calculations that form the basis of the Boeing analysis are valid, but they only put a minimum value on the speed of the guide. Paraphrasing, the Boeing analysis states that if the speed of the airplane was less than 57 mph, there is not enough energy available to shear the pins in the spring guide. It does not state that, if the speed is greater than 57 mph, the pins will shear. That analysis requires the determination of forces applied at specific locations. The second Boeing report on the servo damage addresses forces, but it ignores how those forces could possibly be applied. Neither report addresses the principle of conservation of momentum, which relates mass, speed and time. To get the acceleration needed to fail the spring guide pin, the guide must be slowed from 57 mph to zero speed in approximately 0.000133 seconds, an impossibly small elapsed time considering the size and lack of structural rigidity of the airplane, the fact that it impacted water, and the relative lack of damage to the parts to which the PCA was attached.

Based on a corrected Boeing analysis, most probably, the internal damage to the right outboard PCA servo predated the accident. Because this failure is latent, this damage could have occurred anytime after the last “A” check of the airplane.

With the spring looped over the spring guide and inhibiting the movement of the slide, the slide may be jammed in an off-null position. Hydraulic fluid would then be ported to the PCA ram when the elevator control system would be asking for no flow. The remaining PCA’s would then compensate for this malfunction by porting fluid to the other side of the PCA thereby balancing the system and hiding the defect from the crew.

Appendix A-5
Dynamic Analysis of the Elevator Control System

Introduction

The elevator control system on the B-767 has several unusual characteristics. In particular, the system has the capability to completely separate the left and right sides. This capability is included to allow elevator control if one side becomes jammed. For example, if the right elevator is jammed, the pilot in the left seat can, by exerting enough force, separate the left and right sides and can control the left elevator while the right elevator remains jammed.

This capability to separate the left and right sides of the elevator control system is implemented with the use of two override connections, one between the control columns in the cockpit and the other in the aft quadrant. These override connections will transmit force as a linear spring unless the force being transmitted reaches 25 lbf. When the force reaches 25 lbf, the connection between the left and right columns separates and no force can be transmitted. If the force applied to the aft override connection reaches 25 pounds force, the connection breaks but instead of a complete separation, the left and right sides are then connected by a much weaker spring.

The elevator control system is described by Boeing in Figure A-5.1. In their analysis, Boeing assumed that the masses and the friction are zero because they were performing a static analysis. The Egyptian team confirmed this static analysis. It is correct that the masses and the friction are irrelevant for a static analysis; however, the accident was a very dynamic event. For that reason, any conclusions should be based on a dynamic analysis of the elevator control system.

Analysis

A dynamic analysis of the elevator control system of the B-767 was performed by the Egyptian team. A simulation of the system was programmed into an Excel spreadsheet. The analysis was based on the Boeing description of the system as shown in Figure A-5.1 and included the non-linear characteristics of the breakout connections. That description did not include any information on the masses of the various components or the friction in the system; therefore, those values were assumed. For the description of the dynamic behavior of the system that follows, the masses were all assumed to be to be 2 slugs and the damping coefficients were all assumed to be 5 lbf-s/deg. The sensitivity of the results to variations in these values was also performed.

The simulation was run with a user-determined force applied to the right control column. The force was applied at time equals zero and was held constant for the duration of the simulation. No force was applied to the left control column. Under these conditions, it was found that whether a separation in either quadrant occurred or not depended on the magnitude of the force applied to the right control column.

Figures A-5.2 and A-5.3 show the results of the simulation with a constant force of 32 lbf applied to the right control column. This force is just below the force necessary to cause a separation in the front quadrant override connection. In Figure A-5.2, the forces acting on various parts of the elevator control system are shown. Notice that a separation does not occur. In Figure A-5.3, the positions of both columns and both sides of the aft quadrant are shown. The dynamic behavior of the system is evident in these plots. Also notice that the solution of the static analysis is shown as the constant values after all dynamic motion has dampened out.

Figures A-5.4 and A-5.5 show the results of the simulation with a constant force of 43 lbf applied to the right control column. This force is just below the force necessary to cause a separation in the rear quadrant override connection. In Figure A-5.4, notice that the front quadrant override connection separates at an elapsed time of approximately 0.17 seconds, but the aft quadrant override connection does not separate. This condition also results in a steady state solution comparable to that determined by Boeing in their static analysis.

Figures A-5.6 and A-5.7 show the results of the simulation with a constant force of 44 lbf applied to the right control column. This force is just above the force necessary to cause a separation in the rear quadrant override connection. In Figure A-5.6, notice that the front quadrant override connection separates at an elapsed time of approximately 0.16 seconds, and the aft quadrant override connection separates approximately 1.1 seconds later. As specified by Boeing, the aft quadrant breakout force does not go to zero. Notice also that the position of M_3, which linearly relates to the position of the left elevator, indicated in Figure A-5.7 as “Left Aft Quad,” is near neutral while M_4, indicated in Figure A-5.7 as “Right Aft Quad,” shows a significant trailing edge up position. A split has occurred.

The above analysis used values for the masses and damping coefficients that were assumed because they were known. If the actual values for the masses and the damping are made available, this analysis can be repeated. Because they are not known, a sensitivity analysis was performed to assess the impact of inaccurate assumptions. The masses of the various components were varied from 1 to 30 slugs (32 to 966 lbm or 15 to 438 kg) with all masses set to equal values for each test point. The damping coefficients were varied from zero to 25 lbf-s/deg with each mass having the same coefficient.

Figure A-5.8 presents the effect of varying the damping coefficients with a uniform mass of 2 slugs for each component. Notice that the column force required to separate both override connections never exceeds 53 lbf.

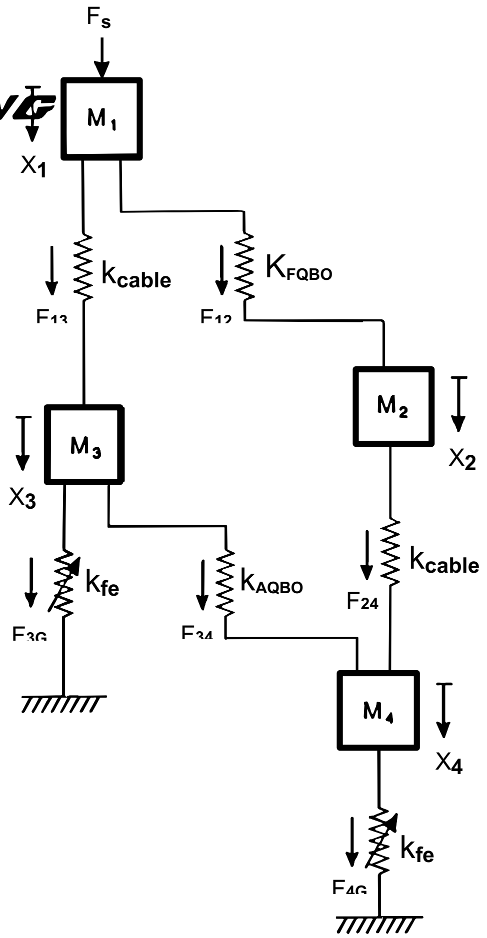
Figure A-5.9 shows the column force required to separate the override connections as a function of the mass of the system with a damping coefficient of 5 lbf-s/deg. Notice that the force required to separate both front and aft is less than 50 lbf for component masses as low as 1 slug. It should be noted that, if the plot were continued to masses near zero, the force required to separate the override connections would increase to very high values. The loading on the aft quadrant override connection requires a mass to resist movement of the elevators. At very low masses, the rear quadrant override connections cannot load up once the front quadrant separates. In the dynamic analysis, the aft quadrant does have mass and, as Newton said, will tend to stay at rest. The result is that the loading on the aft override connection increases beyond the 25 lbf needed for separation.

There is evidence of this failure recorded on the FDR as shown in Figure A-5.10. This figure shows the pitch, vertical load factor, and elevator positions during time around the departure from 33,000 feet. Notice that at 1:49:45, the autopilot turns off, and the right elevator immediately moves approximately 0.6 degrees trailing edge down and the left elevator moves approximately 0.2 degrees trailing edge down. This is a clear indication of one PCA failing and the other two on the right side compensating for the failure. Approximately 8 seconds later, a second PCA on the right elevator fails and the one remaining PCA cannot compensate, so the airplane begins a nose down pitch. At this time, there is no one in the left seat. The vertical load factor decreases dramatically, and the first officer is initially unable to reach the controls. Approximately 1.5 seconds after the pitchover begins, the first officer pulls back on the control column. The front override separates almost immediately but, because of the dynamic behavior of the elevator control system, the rear quadrant override separates later.

Conclusions

This analysis shows that elevator splits can occur. Figures A-5.6 and A-5.7 show a split, but they do not represent the conditions that existed during the accident because there are no malfunctioning PCAs modeled. In the accident, there were additional forces acting on M_4 from the malfunctioning PCAs. The results shown above simply confirm that an elevator split can occur if sufficient force is applied at one control column and the other is left unattended. This result is contrary to results of the static analysis performed by Boeing. It also provides an explanation for why, with the left seat vacant, the first officer could not control the A/C.

Rectilinear Lumped Mass-Spring Model of 767-300 Elevator System



Model Constants:

M_1 = Lumped mass representing captain's control column.
M_2 = Lumped mass representing F/O's control column.
M_3 = Lumped mass representing left aft quadrant (left elevator input).
M_4 = Lumped mass representing right aft quadrant (right elevator input).

For purposes of this document, assume $M_1= M_2= M_3= M_4=0$ since this model is only being used to compute static forces and positions.

Note: All model constants, inputs, and outputs are expressed in pilot units, i.e. degrees of column (deg) and pounds of pilot column force (lbs).

k_{cable} = Stiffness of the control cables connecting each column to its associated aft quadrant = 16.74 lbs/deg for the 767-300.

k_{FQBO}= Stiffness of the forward quadrant breakout mechanism which connects the two control columns together. When $|F_{12}| < 25$ lbs, then k_{FQBO} = 140 lbs/deg. When $|F_{12}| \geq 25$ lbs, then k_{FQBO} = 0 lbs/deg.

k_{AQBO} = Stiffness of the aft quadrant breakout mechanism which connects the two aft quadrants together. When $|F_{34}| < 25$ lbs, then k_{AQBO} = 140 lbs/deg. When $|F_{34}| \geq 25$ lbs, then k_{AQBO} 2.52 lbs/deg.

k_{feel} = Average stiffness of each feel unit. In reality, this stiffness is a non-linear function of aft quadrant position and varies as a function of the feel pressure. For purposes of this document, assume k_{feel} = 13 lbs/deg. For reference, this feel unit stiffness corresponds to the initial feel unit stiffness (±60 lbs of F_s) at a feel pressure of 770 psi.

Damping and friction terms are not included in this model since only the static characteristics of the system are being evaluated.

Model Input (positive sense is indicated by arrow):

F_s = Pilot force applied to the captain's control column (lbs)

Model Outputs (positive sense is indicated by associated arrow):

X_1 = Captain's control column deflection from neutral (deg)
X_2 = First officer's control column deflection from neutral (deg)
X_3 = Left aft quadrant deflection from neutral (deg column). For reference, the left elevator position (in degrees of elevator) with no airloads or faults present = -3.148 * X_3
X_4 = Right aft quadrant deflection from neutral (deg column). For reference, the right elevator position (in degrees of elevator) with no airloads or faults present = -3.148 * X_4
F_{13} = Force transmitted through the captain's control cables (lbs)
F_{12} = Force transmitted through the forward quadrant breakout mechanism (lbs)
F_{24} = Force transmitted through the first officer's control cables (lbs)
F_{3G} = Force transmitted through the left feel unit to structural ground (lbs)
F_{4G} = Force transmitted through the right feel unit to structural ground (lbs)
F_{34} = Force transmitted through the aft quadrant breakout mechanism (lbs)

Figure A-5.1. Boeing's Lumped Mass-Spring Model.

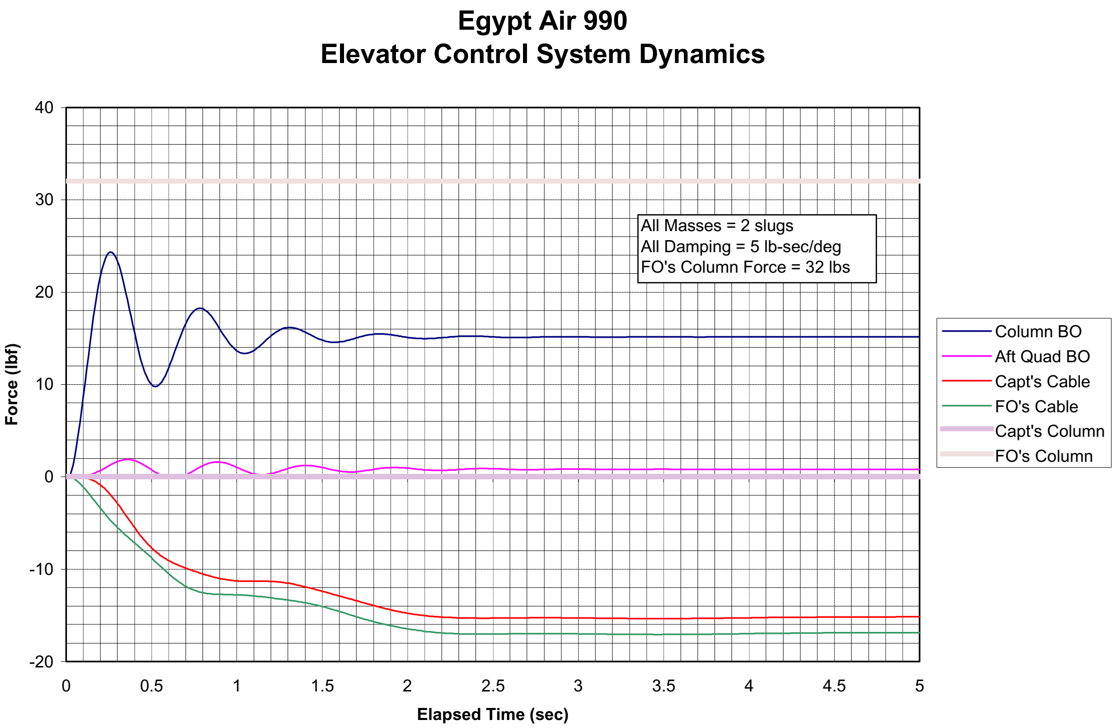


Figure A-5.2. Elevator Control System Forces with Right Column Force of 32 lbf.

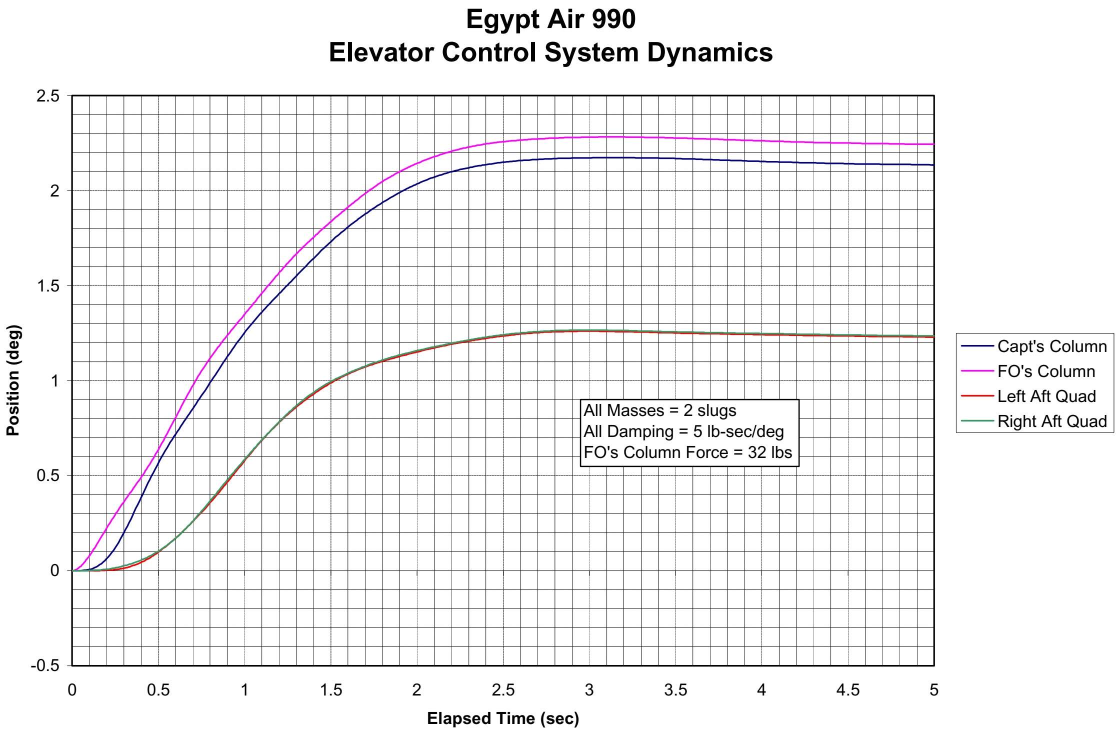


Figure A-5.3. Elevator Control System Positions with Right Column Force of 32 lbf.

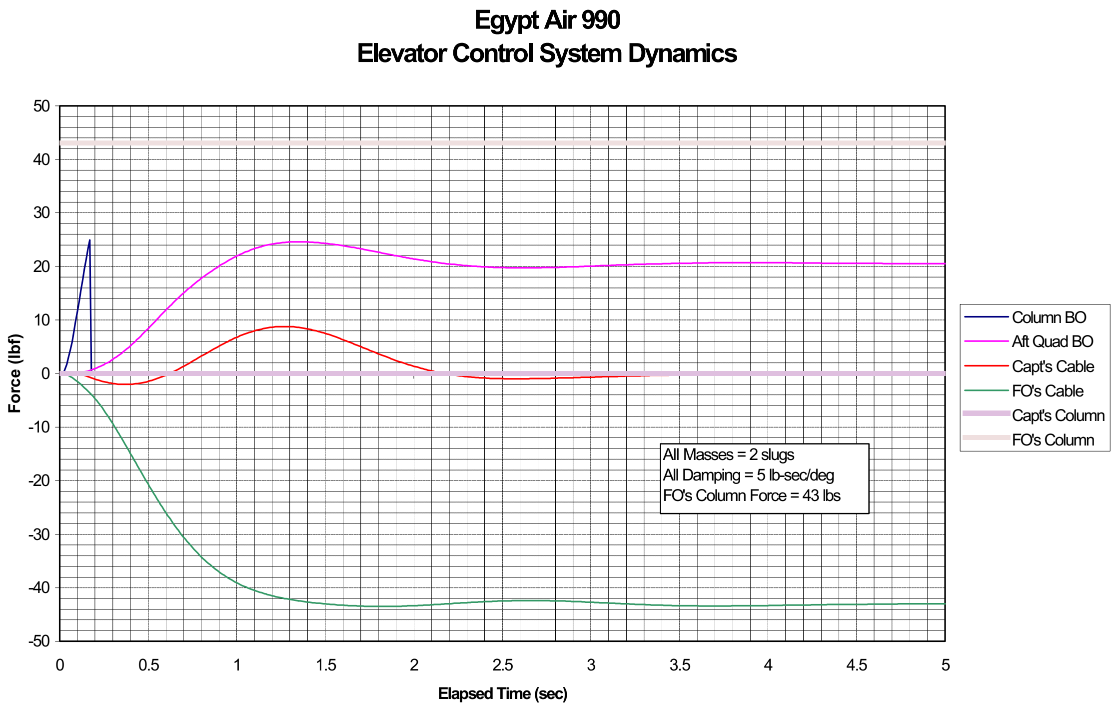


Figure A-5.4. Elevator Control System Forces with Right Column Force of 43 lbf.

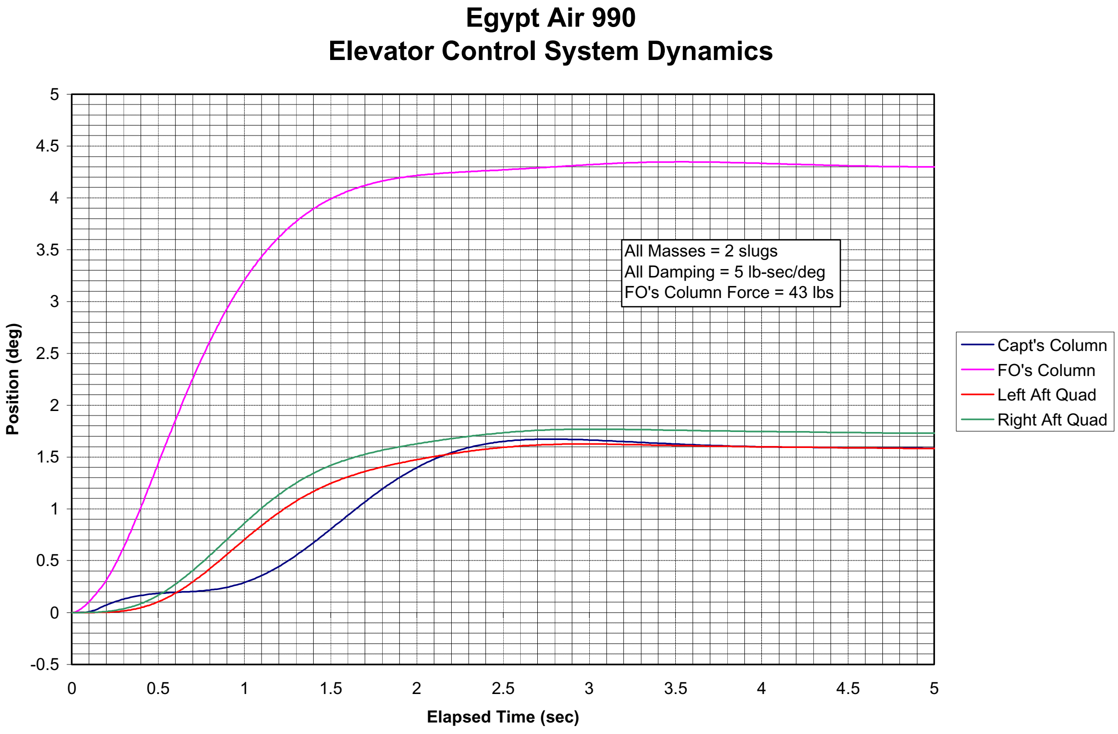


Figure A-5.5. Elevator Control System Positions with Right Column Force of 43 lbf.

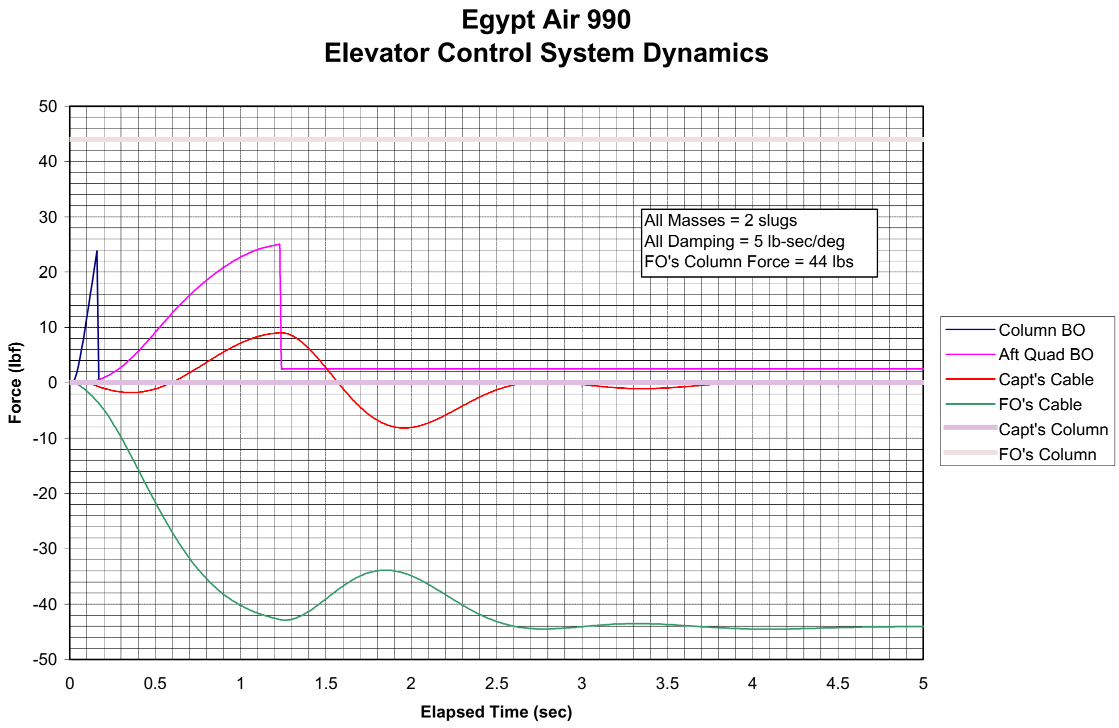


Figure A-5.6. Elevator Control System Forces with Right Column Force of 44 lbf.

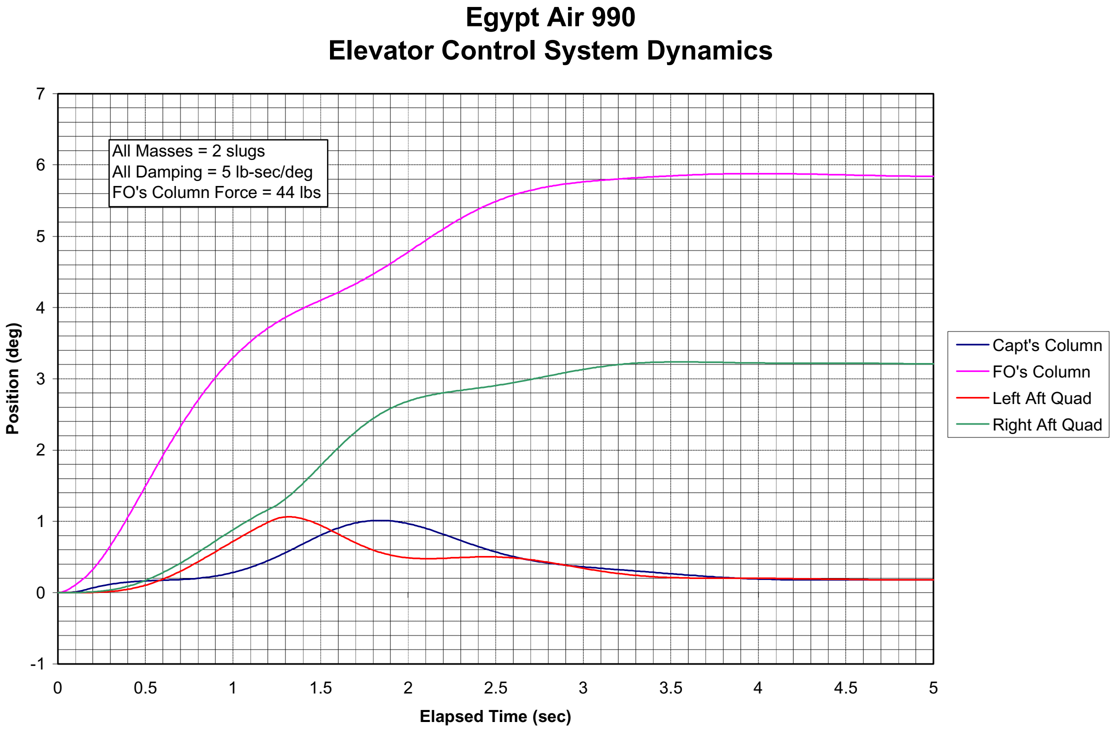


Figure A-5.7. Elevator Control System Positions with Right Column Force of 44 lbf.

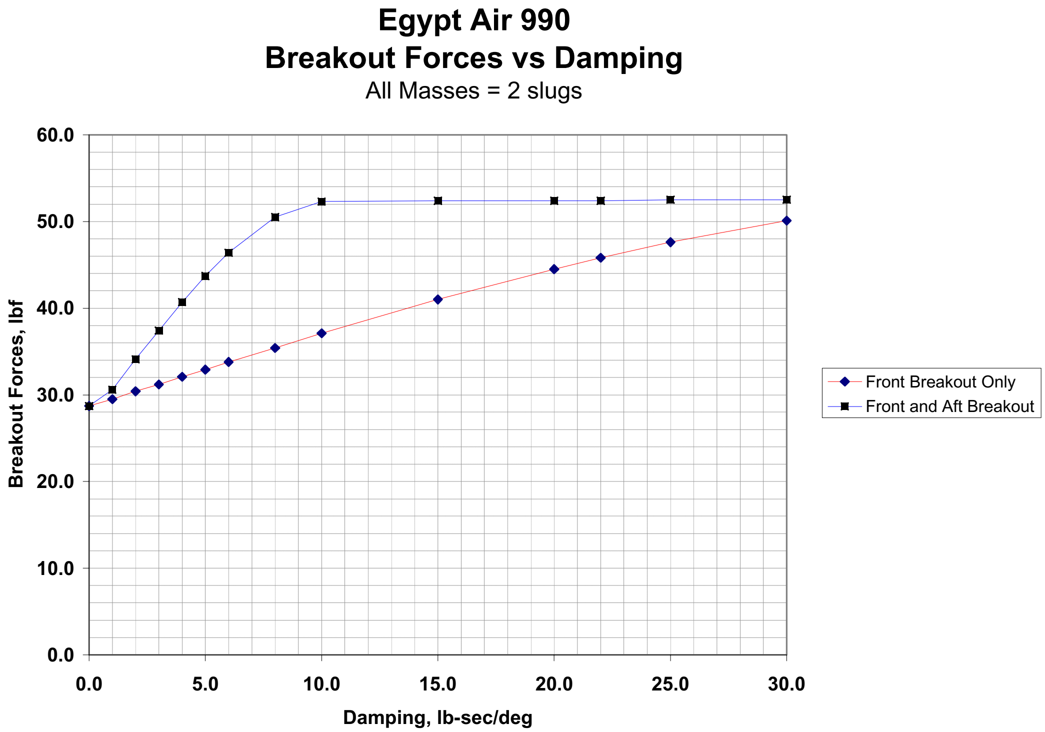


Figure A-5.8. Sensitivity of Breakout Forces to System Damping.

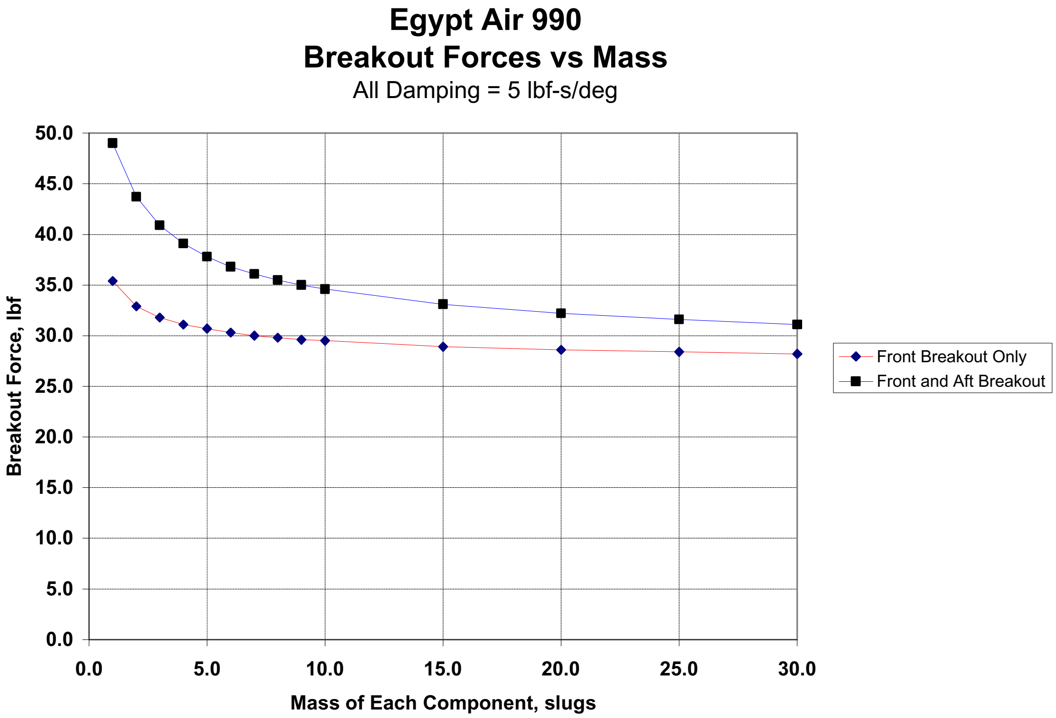


Figure A-5.9. Sensitivity of Breakout Force to System Damping.

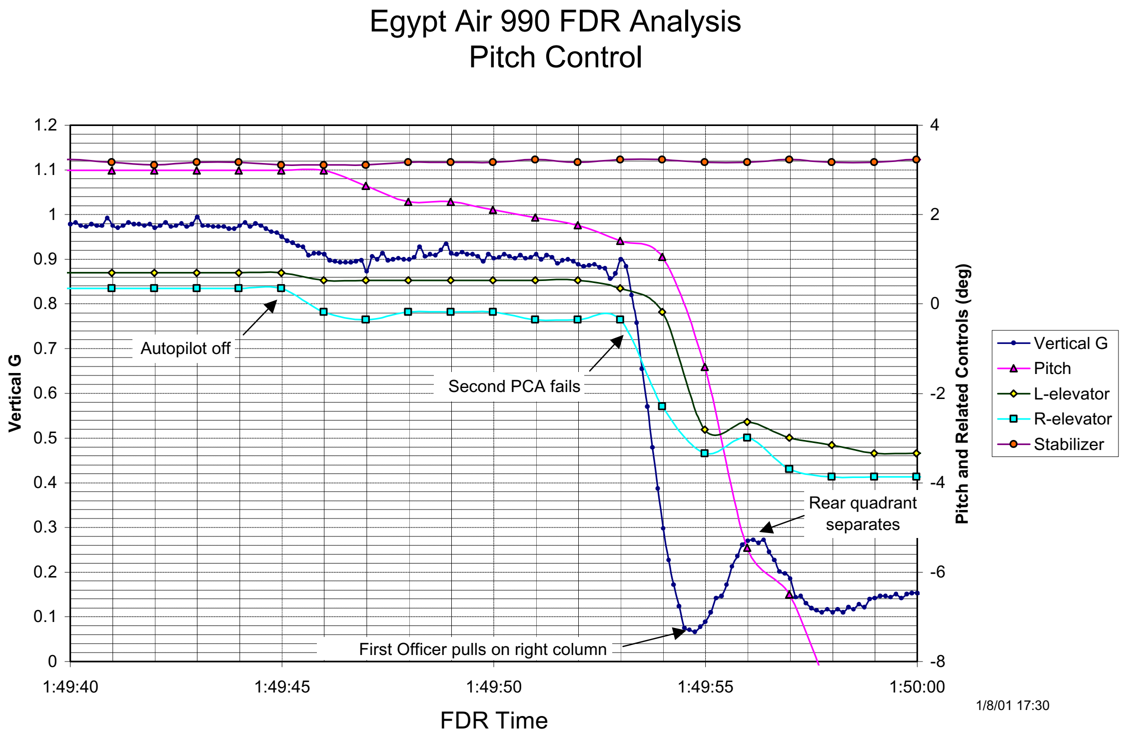


Figure A-5.10. FDR Data Showing Rear Quadrant Breakout.

Appendix A-6
Left Engine Trajectory Analysis

When the wreckage of EgyptAir 990 was found, there were two distinct wreckage locations. The fuselage and most of the rest of the airplane were found in one location and the left engine and related parts were found in a second location. The left engine was found approximately 1200 feet west of the main wreckage site. In addition, the left engine showed significantly less impact damage than the wreckage found in the east recovery area. It was clear that the left engine separated from the airplane well before the fuselage impacted the water and that it hit the water at a much lower speed than the fuselage. A series of trajectory analyses were used to determine the location of separation of the left engine from the rest of the airplane.

If an object is released from an airplane in flight, its trajectory once completely clear of the airplane can be determined using fundamental relationships that are well understood. When initially released from the airplane, the movement of the object can be significantly affected by the local airflow around the airplane. This behavior of the object near the airplane is complex and the subject of a significant research effort in the technical community that studies the release of bombs, fuel tanks, and other objects from airplanes. In brief, the object when released is subject to local flow phenomena that can direct the object back towards the airplane. Once free of the aerodynamic effects of the airplane, the object that has been released is acted upon only by drag and gravity. As in all such analyses, Newton's Second Law of Motion must be strictly observed.

Once completely free from the aerodynamic effects of the airplane, the released object is acted upon by drag and gravity. It is assumed in this analysis that any lift that is produced by the object is negligible; that is, lift in one direction is effectively canceled by lift in the opposite direction as the object tumbles.

Drag is calculated using the drag equation:

$$D = C_D \frac{1}{2} \rho V^2 S$$

where

$C_D =$ Coefficient of Drag

$\rho =$ Local Air Density

$V =$ Local True Airspeed

$S =$ Frontal Area of Object

The drag coefficient of a tumbling object is difficult to determine precisely; however, research has shown that an effective drag coefficient can be estimated. Ragland, et. al. have shown that, for an object like a tumbling jet engine, a reasonable value for effective drag coefficient is approximately 70% of the drag of a non-rotating engine orientated with its maximum area (200 ft^2) exposed to the relative wind. A value of 1.0 was used for the drag coefficient of the non-rotating engine, so an effective value of 0.7 was used in this analysis.

Using the above physical relationships, a family of trajectories for the left engine of EgyptAir 990 were determined for a variety of release points in the reconstructed flight path. The release point that results in an engine impact point that is the closest to the East recovery site defines the latest point at which the fuselage and engine separated. The engine may have separated earlier than this point and remained in close proximity to the fuselage due to aerodynamic interaction with the fuselage, but it could not have separated later than this point.

Figure A-6.1 shows the family of engine trajectories for different separation points. Notice that one trajectory results in an impact point very close to the East recovery site. This trajectory began at an altitude of 22,000 feet MSL, which is well before the top of the climb. The engine separated from the airplane at some point prior to this altitude, but how much prior to this altitude is impossible to determine because the effects of aerodynamic interaction between the engine and the fuselage is not known. Trajectories that begin prior to this point result in engine impact points that are too far to the west. Trajectories that begin after this point result in impact points too far south and east. In particular, it is impossible for the engine to separate from the airplane while in the dive" and impact the water at the west recovery site.

Analysis of the recovered left engine mount showed that the engine separated from the airplane by rotating to the left and down. Just before the separation, the airplane was traveling at a speed approaching the speed of sound and experiencing a load factor in excess of 2.5. Because of a lack of experimental data at those speeds, the forces acting on the engine mounts under those conditions have not been calculated, but they are certainly well beyond normal operating conditions.

When the engine separated from the airplane, two important things happened. First, the drag on the left side suddenly decreased significantly. Second, at least one hydraulic system became completely disabled. The sudden decrease in drag surely caused a large yawing moment to the right. Because of the swept wings, this yaw resulted in a large rolling moment to the right. The resulting right bank is reflected in the right turn in the flight path that is shown following the separation of the engine.[38]

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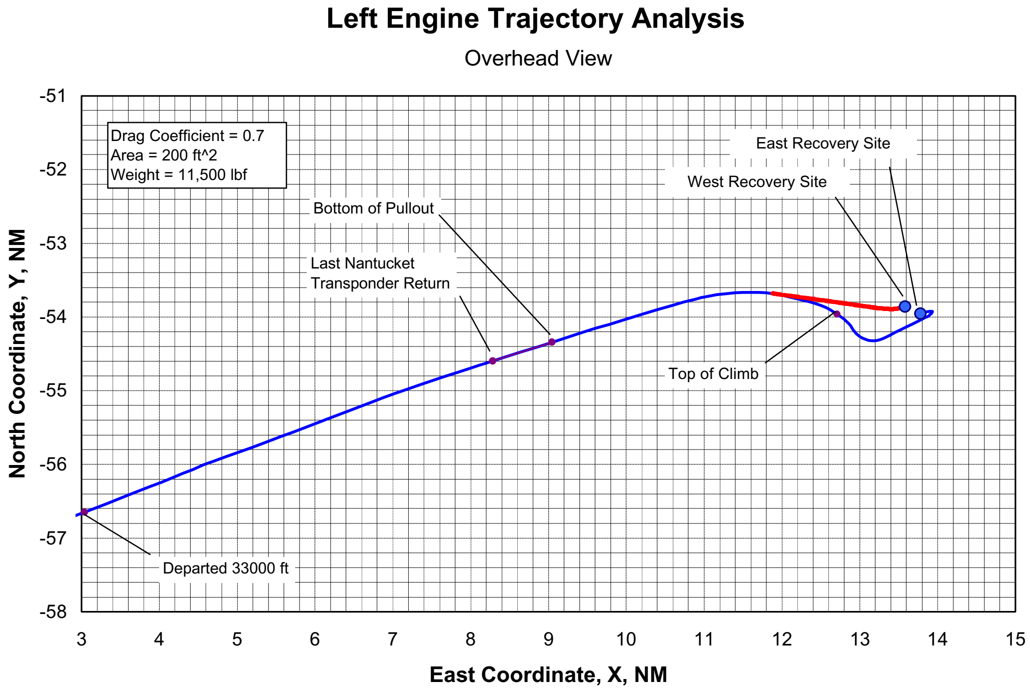
[38] References: Ragland, K. W., Mason, M. A., and Simmons, W. W., "Effect of Tumbling and Burning on the Drag of Bluff Objects", Jour. Of Fluids Engrg. vol. 105, June 1983, pp. 174-178.



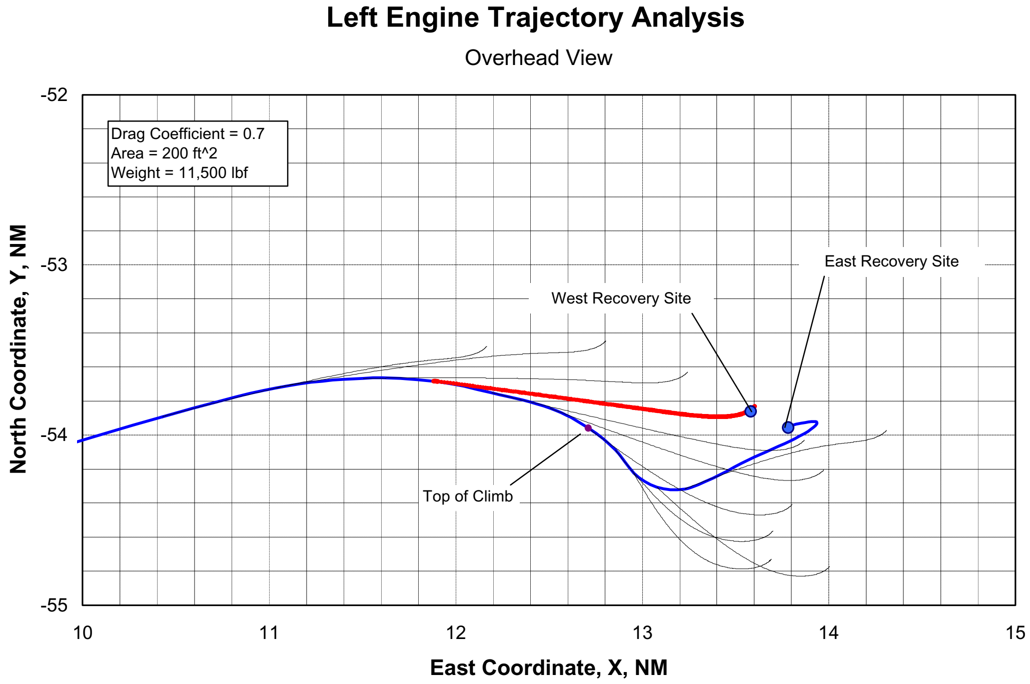


Figure A-6.1. Trajectory Analysis for Left Engine.

Appendix A-7

Hydraulic Lab and Simulator tests conducted March 2001[39]

Background:

In March 2001, NTSB informed the Egyptian Investigation Team that it has recently discovered some errors in modeling the PCU dynamics during blowdown and blowback situations. The NTSB requested that Boeing develop a revised model and re-evaluate the effects of the failure in the simulator. The NTSB stated that an "omission" in the model was identified that resulted in incorrect calculations of the position of the failed elevator. The missing elements in the PCU model are the relief valves shown in the PCU schematic in Figure A-7.1

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[39] Reference Boeing letter B- H200- 17236- ASI dated 03 May 2001, "Test and Simulation Report"

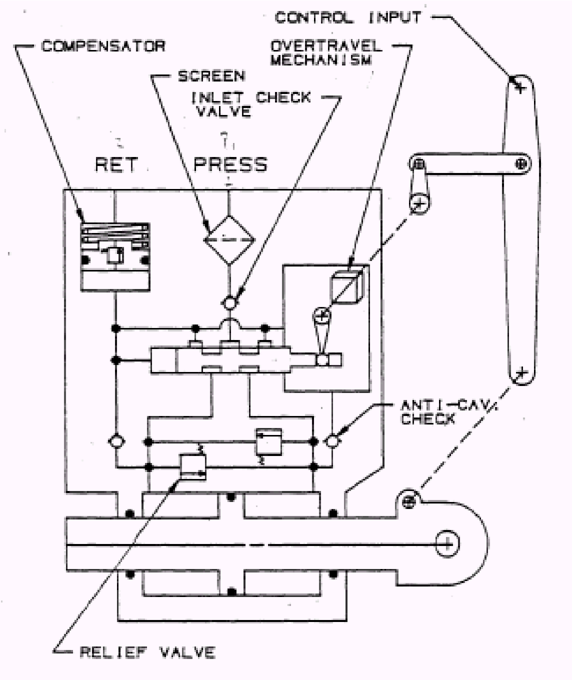

Figure A-7.1 Elevator Hydraulic System

A Bench Test was conducted on March 22 and another E-Cab tests were conducted on March 23, 2001 at Boeing Field, Seattle.

The Egyptian Investigation Team requested to have the detailed test description and results available for their inspection and analysis. In particular, they requested a complete accounting of all changes, assumptions, engineering data, limitations, constraints, etc. in addition to a complete set of test results in paper and electronic format. The Egyptian Investigation Team received Boeing letter B- H200- 17236- ASI dated 03 May 2001, “Test and Simulation Report” after about 6 weeks.

The Egyptian Investigation Team also asked Boeing to forward an update to its officially received document D613T161 (B767 Simulator Data) to reflect the error discovered by Boeing in modeling the PCU dynamics during blowdown and blowback situations. No update has been yet received from Boeing.

When alerted that new E-Cab testing was to be accomplished, the Egyptian Investigation Team asked the NTSB to include other effects influencing the elevator behavior with elevator failures modeling (which were ignored in the previous simulator tests), including the following:

- The exact 767 Elevator Systems Operation with Regard to Column Splits, Aft Quadrant Splits and Column Jams as described in Boeing Report B-H200-17083 dated 20 October 2000 considering the non-linear feel unit stiffness characteristics. (Refer also to Boeing report B-H200-17026-ASI, dated 2 August 2000, "767 Elevator System Operation with Regard to Column Splits, Aft Quadrant Splits, and Column Jams")
- Use of exact gearing ratio between the elevator and column (Refer to Boeing Report B-H200-17027-ASI, dated 4 August 2000, "Explanation of Two 767 Elevator System Characteristics Observed During Dual PCA Fault Ground Testing", however the ground test showed a gearing value of 3.106 "fig 62").
- The three factors influencing the elevator surface deflection as mentioned in Boeing report B-H200-17027-ASI, dated 4 August 2000, "Explanation of Two 767 Elevator System Characteristics Observed During Dual PCA Fault Ground Testing" which are:
    - The stiffness of the elevator system components.
    - The location of the elevator position sensor.
    - The PCA location chosen to insert the fault.
- The Elevator System Friction and Hysteresis as per Boeing report B-H200-17028-ASI dated 7 August 2000, (767 Elevator System Friction and Hysteresis).

- The induced forces as the result of inserting the elevator malfunctions adjusted to the ground tests actual results.
- The Effect of high rate column input {Boeing report B-H200-17065-ASI "Effect of high rate column input", dated Sep 29,2000)
- Elevator system response to hydraulic On (Boeing report B-H200-17076-ASI "Elevator system response to hydraulic on", dated 16 October, 2000.

In response to these requests, the NTSB stated verbally that these effects will <u>not</u> be considered in the E-Cab tests but will be added to the list of simulator limitations.[40]

Analysis:

- Boeing, in their analysis, used only one dual PCA jam combination scenario (failure of middle and outboard PCA's), ignoring the two other probabilities. The results could be quite different because of the differences in the relief valve cracking pressures, the valve resetting pressures, the internal leakage rates.
- Boeing stated that after the elevator blowdown and with the increase in aircraft speed, the elevators displacement would be more TED than previously reported because of the internal leakage within the relief valve of the non-failed PCA. The reasoning behind this finding as mentioned in Boeing letter is that the leakage will cause a position equivalent to one full PCA acting TED, not the effective 80% PCA position previously reported. There are several problems with this new finding:

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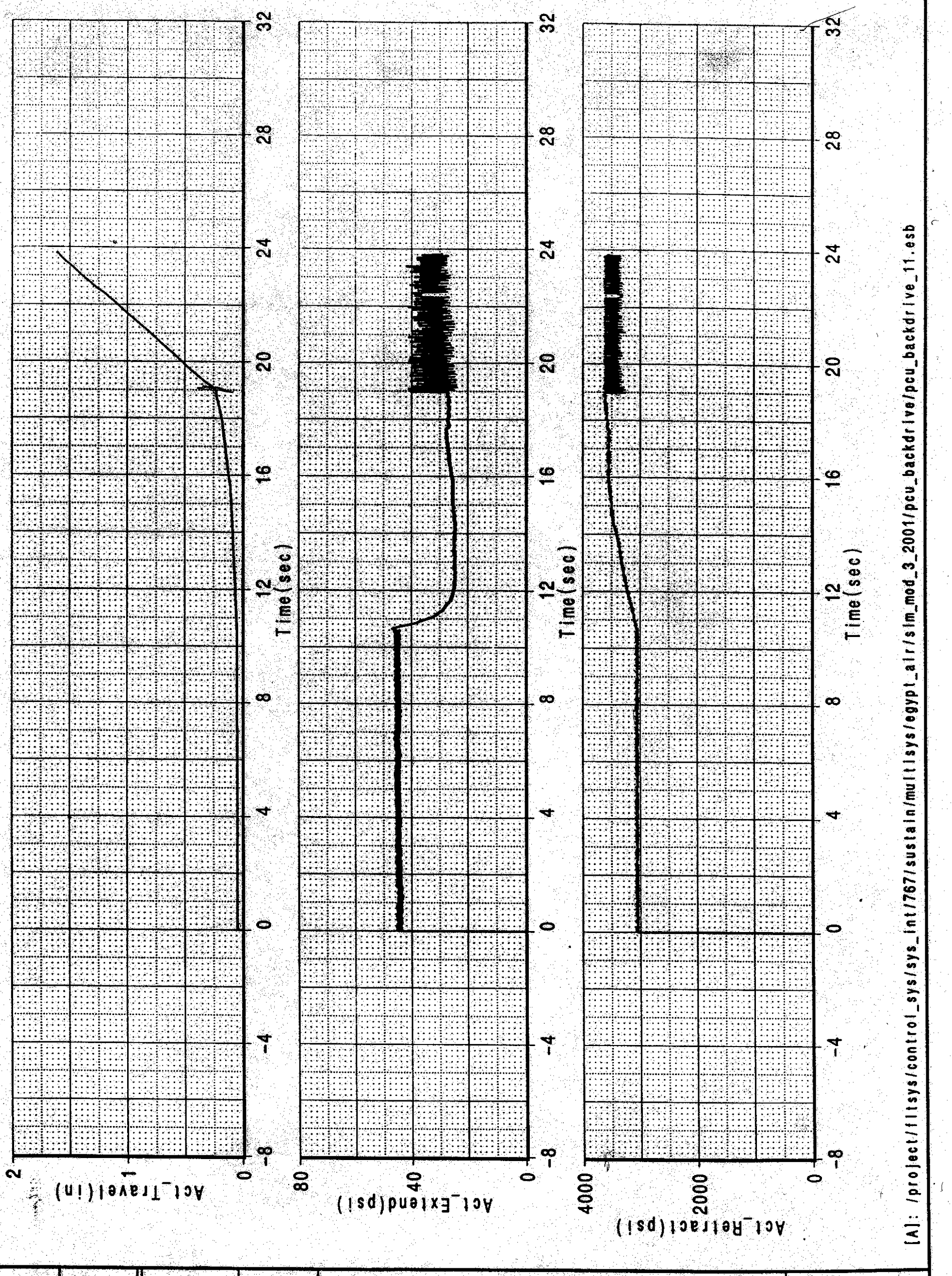
[40] Boeing letter did not contain any information regarding the Egyptian Investigation Team requests for adjusting the simulator modeling, also did not contain the NTSB statement to consider these requests as simulator limitations.

  - The timing for transfer from the case of "elevator moving from neutral" to the case of "elevator steady state position" is function of the non-failed PCA relief valve internal leak rate. By ignoring this leak rate, they used an infinite leak rate resulting in almost an instantaneous change. This leads to completely improper and misleading results.
  - In the case of "elevator moving from neutral" to the case of "elevator steady state position", the failed actuators are subjected to internal leakage from the high pressure side of the PCA chamber to the low pressure side through the PCA actuator piston seals. This leakage will result in further upward movement of the right elevator driving the elevator towards the FDR recorded schedule, contrary of the effect of internal leak at the non-failed PCA relief valve. These effects are not shown in Boeing letter.
  - The effect of internal leakage at other hydraulic elements such as the inlet check valve has been ignored.
  - Figure 16 in Boeing report (Figure A-7.2) shows that during the lab test, the PCA started retraction with increasing retraction pressure before opening of the PCA relief valve (about 0.2 inch) in contrary with Boeing assumptions.
- In Boeing letter, it is assumed that the events occur in three distinct successive phases as follows:
  1) Movement away of neutral
  2) Steady state position
  3) Movement toward neutral.

The transition from phase 1 to phase 2 is dependent on the internal rate leak of the non-failed PCA within the relief valve and the actuator piston seals. (Boeing assumed almost an instantaneous change). During this transition period, the aerodynamic forces will drive the elevator surface towards the neutral point (phase 3), overlapping with phase 2. This overlap is not taken into account in Boeing letter. Ignoring this overlap might lead to completely improper conclusions.

Based on the above analysis, Egyptian Investigation Team believes that no conclusion can be based on these tests because (1) the acknowledged limitations of the E-Cab simulator, (2) the selective application of assumptions, and (3) the use of data that has not been accurately validated.



CALC	B.Richardson	19Apr01	REVISED	DATE	Egypt Air Flt 990 Accident Investigation PCU Backdrive Lab Test "Const Load" PCU Retract to Extend BOEING	EQA Lab 767 PCA
CHECK						Test Date 3/21/01
APPD.						PAGE Figure 16
APPD.						

Figure A-7.2 PCA Backdrive Lab Test (PCA retraction)

Appendix A-8

EgyptAir Flight 990, October 31, 1999
Reports and Other Investigative Material for the Docket

Note: This list consists of material in the docket as of August 2, 2000 and subsequently added up to April 2, 2001.
The full docket system is not accessible online at this time; however, a complete list of items is available upon request
(see Contacts and Information Sources)

All documents listed below are in the Adobe Portable Document Format (PDF) and require the free Acrobat Reader 3.0 from Adobe or later for viewing; when printing, use the "shrink-to-fit" Adobe print option for best results. (File size is less than 3MB, unless otherwise indicated.)

Exhibit 2 - Operational Factors

Group Chairman's Factual Report

Addendum 1 to Factual Report: B767 initial crew training records for Capt. El Habashy

Addendum 2 to Factual Report: B767 initial crew training records for F/O El Batouty *(11M)*

Addendum 3 to Factual Report: Copy of EgyptAir Flight 990 Loadsheet

Letter from Captain Mohsen El Missiry, dated 7/27/00,
Egyptian Delegation comments on Operational Factors Group Chairman's Factual Report Addendum #3

Exhibit 3 - Air Traffic Control

Group Chairman's Factual Report

- *Attachment A:* ATC Voice Transcripts
- *Attachment B:* North Atlantic Track Advisory Message
- *Attachment C:* Copies of ZNY Flight Progress Strips on MSR990
- *Attachment D:* Kennedy Seven Departure Chart
- *Attachment E:* Excerpts from ZNY Standard Operating Procedures Manual
- *Attachment F:* ZNY Control Room Layout Diagram
- *Attachment G:* Enroute Aeronautical Chart
- *Attachment H:* North Atlantic Route Chart, Tracks Drawn by Group Member Hruz
- *Attachment I:* ZNY Accident/Incident Notification Record, Form 8020-3

- *Attachment J:* ZNY Daily Record of Facility Operation
- *Attachment K:* ZNY DART and NTAP extraction printouts
- *Attachment L:* FAA Order 7110.65 Chapter 10, Sections 3 and 4
- *Attachment M:* Warning Area Logs, FAA, US Navy
- *Attachment N:* Letter of Agreement, FAA and US Navy, Special Use Airspace

Addendum 1: ZNY Sort Box

Addendum 2: Updated Attachments

Letter from Captain Mohsen El Missiry, dated 7/27/00,
transmittal of June 18, 2000, letter from A. V. M. Abdelfattah Kato, Chairman, Egyptian Civil Aviation Authority, to Jane F. Garvey, Administrator, Federal Aviation Administration

Letter from Captain Mohsen El Missiry, dated 7/31/00,
Egyptian Delegation comments on Air Traffic Control Group Chairman's Factual Report

Exhibit 5 - Meteorology

Group Chairman's Factual Report

- *Attachment 1:* 0000Z sounding on October 31, 1999, in graphic and alphanumeric format
- *Attachment 2:* 0647:09Z radar image at the 0.5 degree elevation scan
- *Attachment 3:* 0649:44Z radar image at the 1.5 degree elevation scan
- *Attachment 4:* 0652:19Z radar image at the 2.5 degree elevation scan
- *Attachment 5:* 0657:01Z radar image at the 0.5 degree elevation scan
- *Attachment 6:* 0659:36Z radar image at the 1.5 degree elevation scan
- *Attachment 7:* 0702:11Z radar image at the 2.5 degree elevation scan
- *Attachment 8:* infrared band 4 image at 0645Z at 4X magnification
- *Attachment 9:* band 2 infrared image at 0715Z on October 31, 1999
- *Attachment 10:* water vapor images at 0645Z on October 31, 1999
- *Attachment 11:* water vapor images at 0715Z on October 31, 1999

Exhibit 7 - Structures

Group Chairman's Factual Report

- *Appendix A:* Major Assembly Breakdown
- *Appendix B:* Hangar Layout
- *Appendix C:* Fuselage Stations
- *Appendix D:* Wing Stations
- *Appendix E:* Engine Pylon Diagram
- *Appendix F:* Horizontal Stabilizer Stations
- *Appendix G:* Vertical Fin Stations
- *Appendix H:* Photographs *(4.5M)*
- *Appendix I:* Tables

Addendum 1 to Factual Report

- Appe*ndix A:* Photographs

Exhibit 8 - Powerplants

Group Chairman's Factual Report

- *Appendix 1:* Photographs *(4.8M)*
- *Appendix 2:* EgyptAir Engineering Section's life limited component list for PW4060 engine SN 724127
- *Appendix 3:* Safety Board's Materials Laboratory Report No. 00-030, dated February 2, 2000
- *Appendix 4:* Saybolt Laboratory results of testing JFK fuel
- *Appendix 5:* Core Laboratory results of testing LAX fuel
- *Appendix 6:* Boeing letter, dated February 11, 2000, regarding Engine Fuel Flow FDR Data
- *Appendix 7:* Pratt & Whitney letter, dated November 30, 1999, regarding effects of negative-G operation on PW4060 engine and copy of type certificate data sheet
- *Appendix 8:* Boeing data sheet on results of 767/PW4000 negative-G flight test

Letter from Captain Mohsen El Missiry, dated 7/27/00,
Egyptian Delegation comments on Powerplants Group Chairman's Factual Report

Letter from Mr. Michael Barton, Pratt & Whitney, dated 8/18/00,
regarding clarification on electronic engine control channel switchover

Exhibit 9 - Systems

Group Chairman's Factual Report

Appendix A: Photographs

Addendum 1: Teardown of Two Escape Slide Actuator/Integrator Assemblies

- *Appendix A:* Photographs

Addendum 2: Teardown of Selected Longitudinal Control System Components

- *Appendix A*: Photographs *(10.7M)*

Addendum 3: Examination of Additional Wreckage Recovered During the Second Recovery Effort

Addendum 4: Ground and Simulation Testing

- *Appendix A:* 767-400ER Elevator System Changes Relative to the 767-300ER
- *Appendix B:* Test Item Planning Sheet B1.39.1316 Rev. A for the 767 Elevator Dual Failure Ground Test
- *Appendix C:* Selected Representative Time History Plots for the 767 Elevator Dual Failure Phase I Ground Tests
- *Appendix D:* Selected Representative Time History Plots for the 767 Elevator Dual Failure Phase II Ground Tests
- *Appendix E:* Explanation of Bias in the Column Force Data, a Method for Correcting the Bias, and Re-Plotted Data From Both Phases I and II that is Corrected for the Bias *(6M)*
- *Appendix F:* Simulator Features and Capabilities Added to Support the 767 Elevator Dual Failure Simulation Tests
- *Appendix G:* Simulator Log
- *Appendix H:* Selected Representative Time History Plots for the 767 Elevator Dual Failure Simulation Tests

Addendum 5: Documentation of Servovalve Input Linkages

- *Appendix A*: Exploded and Overall Views of the Example Servovalve Input Linkage Components
- *Appendix B:* Photographs of the Servovalve Input Linkage Components from the Modified Power Control Actuators used in the Ground Tests *(4M)*

- *Appendix C:* Photographs of the Servovalve Input Linkage Components from the Accident, SU-GAP

Letter from Ronald J. Hinderberger, Boeing Commercial Group, dated 7/21/00,
"Split Elevator Failure Scenario - EgyptAir 767-300ER SU-GAP, Accident Off Nantucket, Massachusetts 31 October, 1999"

Letter from Captain Mohsen El Missiry, dated 7/27/00,
Egyptian Delegation comments on System Group Chairman's Factual Report

Letter from Captain Mohsen El Misery, dated 7/27/00,
Egyptian Delegation comments on Systems Group Chairman's Factual Report Addendum regarding ground and simulation testing (revised addendum 4)

Letter from Captain Mohsen El Missiry, dated 6/29/00,
Egyptian Delegation comments on Systems Group elevator hardware examination and analysis

Letter from Captain Mohsen El Missiry, dated 7/29/00,
Egyptian Delegation comments on System Group Chairman's Factual Report, "Study regarding System Group activities and summary of the elevator mechanical failure," and "Detailed study of the elevator mechanical failure (Exhibit A)"

Letter from Captain Mohsen El Missiry, dated 8/16/00,
Egyptian Delegation comments regarding the Boeing letter B-H200-17031-ASI, dated August 11, 2000 (Mach Trim System)

Exhibit 10 - Flight Data Recorder

Group Chairman's Factual Report

- *Attachment 1:* List of Recorded Parameters
- *Attachment 2:* Photographs of Damaged FDR
- *Attachment 3:* EgyptAir Flight 990 FDR Tabular Data Sets
- *Attachment 4:* Plots of EgyptAir Flight 990 FDR Data
- Addendum 1 to Factual Report
- Flight Data Recorder and Cockpit Voice Recorder Overlay Study
- *Attachment I:* Selected FDR Data in Graphical Format from 1:49:40 EST to 1:50:35.98 EST
- *Attachment II:* Selected FDR Data in Graphical Format from 1:47:40 EST to 1:49:40 EST

Letter from Captain Mohsen El Missiry, dated 7/14/00,
Egyptian Delegation comments on Flight Data Recorder Factual Report

Letter from Captain Mohsen El Missiry, dated 7/27/00,
Egyptian Delegation comments on Flight Data Recorder Group Chairman's Factual Report

Exhibit 11 - Maintenance Records

Group Chairman's Factual Report

Exhibit 12 - Cockpit Voice Recorder

Group Chairman's Factual Report-Transcript

Transcript in Arabic

Sound Spectrum Study

- *Attachment I:* Spectrum Plots

Exhibit 13 - Performance

Group Chairman's Performance Study

Addendum 1

Addendum 2*(5M)*

- Errata *(added 30-Aug-00)*

Addendum 3
List of Radar Data Files

List of E-CAB Simulator Plot Files

Letter from Captain Mohsen El Missiry, dated 7/27/00,
Egyptian Delegation comments on Group Chairman's Performance Study

Letter from Captain Mohsen El Missiry, dated 7/27/00,
Egyptian Delegation comments on Group Chairman's Performance Study Addendum 1

Exhibit 14 - Human Performance

Group Chairman's Factual Report

- *Attachment 1:* Interview Summaries

- *Attachment 2:* Egyptian Civil Aviation Regulation (ECAR) Part 67: Medical Standards and Certification
- *Attachment 3:* Egyptian Civil Aviation Authority Medical Board Summaries of Flight Crew Medical Histories
- *Attachment 4:* Hotel Record Summary
- *Attachment 5:* Correspondence
- *Attachment 6:* Records of Telephone Conversations and Meetings
- *Attachment 7:* Summary of Activities to Contact Flight Crew Family Members in Egypt
- *Attachment 8:* Excerpt on Egypt from 1999 CIA World Factbook

Addendum 1 - Correspondence

Addendum 2 - Questionnaire Responses

Addendum 3 - FBI Interviews *(5M)*

Addendum 4

Simulation Study

- *Appendix A:* Flight Deck Reference Data

Speech Examination Study
Addendum

Letter from Captain Mohsen El Missiry, dated 7/11/00,
Study Report Regarding Captain Gamil El Batouty, EgyptAir Accident Flight 990 prepared by Dr. M. Adel Fouad M.R.C. Psych. London Consultant Psychiatrist

Letter from Captain Mohsen El Missiry, dated 7/31/00,
Egyptian Delegation comments on FBI interviews

Exhibit 15 - Metallurgy

Report #00-071 - Servo Slide and Sleeve, Bellcrank *(9.5M)*

Report #00-084 - Jackscrew Examination

Report #00-108 - PCA #3 - Servo Slide and Sleeve, Bias Spring, Spring Guide

Report #00-148 - Errata/Addendum Report

Exhibit 16 - Security Factors

Federal Aviation Administration Memorandum, dated 1/14/00,
"EgyptAir Flight 990 Wreckage Inspection, Field Notes of the Federal Aviation Administration Explosives Unit, ACS-50"

Other

Boeing Submission to the NTSB on the EgyptAir 990 investigation, dated October 31, 2000

Correspondence from Pratt & Whitney, dated October 6, 2000

Egyptian Delegation Presentation for Flight MS990 Accident, April 28, 2000

Letter of transmittal from Captain Mohsen El Missiry, dated September 13, 2000,
and attachment: EgyptAir's submission to the National Transportation Safety Board's public docket of the investigation of the crash of EgyptAir flight 990 on October 31, 1999

Response of EgyptAir to October 31, 2000 Submission of the Boeing Company

EgyptAir Flight 990
NTSB Home | News and Events

Appendix A-9

Investigation Participants

Supervision

A.V.M / Abd El-Fatah Kato	Delegated Egyptian Government Supervisor
Capt / Hassan Musharafa	Delegated EgyptAir Supervisor

Investigation Team

Capt / Mohsen El-Missiry	Chief Of Investigation Team (Accredit Rep.)
Capt / Shaker Kelada	Head Of EgyptAir Investigation Team
Eng / Mohamed Abdel Hamid Hamdy	
Eng / Waguih Sobhi	
Eng / Mohamed Sabry Mahmoud	
Eng / Hani Salaheldin	

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Mr/ Fathy Naser
Eng/ Hussin El-Saify
Eng/ Gebaly Hussin
Eng/ Ismail Ibrahim
Eng/ Abd El-Meseeh Adly Fouad

Dr. Adel Fouad
Eng/ Mostafa El-Gammal
Eng/ El-Sayed El-Badwi
Eng/ Ehab Shaker
Eng/ Amr El-Semary
Eng/ Mohamed El-Bakry
Eng/ Fatma Ismail
Mr/ Yousef Hassan

Approved By:

A.V.M / Abd El-Fatah Kato
Delegated Egyptian Government
Supervisor

A.V.M/ Mamdouh Heshmat
Executive Chairman Egyptian
Civil Aviation Supervisory Authority

Prof.Dr/ Ibrahim El-Dimeery
Minister of Transport
Chairman Board of Directors
Egyptian Civil Aviation
Supervisory Authority