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CIVIL AVIATION ADMINISTRATION OF CHINA

AIRCRAFT ACCIDENT REPORT

Controlled Flight Into Terrain
KOREAN AIR FLIGHT KE6316
MD-11F, HL7373
SHANGAHI, PEOPLE'S REPUBLIC OF CHINA
APRIL 15, 1999

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Abbreviations:

AND	Airplane Nose Down
ANU	Airplane Nose Up
A/P	Auto-Polit
ATC	Air Traffic Control/ Air Traffic Controller
CAAC	Civil Aviation Administration of China
CAWS	Central Aural Warning System
CFIT	Controlled Flight Into Terrain
CVR	Cockpit Voice Recorder
DME	Distance Measuring Equipment
DNA	Deoxyribonucleic Acid
ECA:	East China Administration.
EEC	Electronic Engine Controller
FCP	Flight Control Panel
FD	Flight Director
F/O	First Officer
GPWS	Ground Proximity Warning System
ICAO	International Civil Aviation Organization
ILS	Instrument Landing System
KCAB:	Korean Civil Aviation Bureau
MOCT	the Ministry of Construction and Transportation of the Republic Korea
MSL	Mean Sea Level
ND	Navigational Display
NDB	Nondirectional Beacon
NEC	Nippon Electric Company
NTSB	National Transportation Safety Board of the United States
PFD	Primary Flight Director

QAR	Quick Access Recorder
SID	Standard Instrument Departure
SSCVR	Solid State Cockpit Voice Recorder
SSR	Secondary Surveillance Radar
TED	Trailing Edge Down
TEU	Trailing Edge Up
UFDR:	Universal Flight Data Recorder
UTC	Coordinated Universal Time
VOR	Very high frequency Omnidiectional Radio Ranger

Executive Summary

On April 15, 1999, about 16:04'35" Beijing local daylight time (0804:35UTC time), Korean Air cargo flight KE 6316, a McDonnell Douglas MD-11F, Korean registration HL7373, crashed at a construction site near XinZhuang town, MingHang district, Shanghai, 3 minutes after taking off at Shanghai HongQiao International Airport. Flight KE6316 was operating in China airspace as a regularly scheduled international cargo flight from Shanghai (China) to Seoul (Korea). The airplane was totally destroyed by high energy impact forces and a postcrash fire.

After the accident, the Shanghai local government immediately organized and then dispatched an emergency rescue team to the crash site. The site was tightly secured by militarily police. The Civil Aviation Administration of China (CAAC) forwarded notification of the accident to the International Civil Aviation Organization (ICAO), the U. S. National Transportation Safety Board (NTSB) and the Korean Civil Aviation Bureau (KCAB). Under the authorization of the CAAC, as the state of the occurrence, the East China Administration (ECA) of the CAAC established a joint investigative team in accordance with the provisions of ICAO Annex 13. The joint investigative team consisted of investigators of CAAC, public security agents of China, the accredited representatives from the United States and the Republic of Korea and their technical advisers. The joint investigative team received technical support from the KCAB, the NTSB, the FAA, Boeing Commercial Airplane Group, Pratt and Whitney Engines, Korean Air, and other component manufacturers during the course of the investigation.

The joint investigative team made a thorough search in the crash site, and found the memory circuit board of the Solid State Cockpit Voice Recorder (SSCVR) and pieces of tape from the Quick Access Recorder (QAR). The investigative team sent an investigator with the SSCVR's memory circuit board, portions of the QAR tape, and the Electronic Engine Controllers (EEC) to the NTSB laboratory for further analyses. The whole contents of the SSCVR were retrieved in a common effort by the CAAC, the NTSB, and the KCAB. A joint bulletin, of the Korean Air KE6316 Shanghai accident on April 15,1999, signed by the CAAC, the NTSB and the KCAB, was released at 18:00 (Beijing time) on April 27, 1999, which excluded the possibilities that the accident was caused by any explosion, sabotage or the ATC mishandling.

Despite the efforts for more than half a year by the NTSB and the QAR manufacturer, no data could be retrieved from the recovered pieces of the tapes due to their serious damage.

The investigative team made an oversight trip to the Korean Air for its safety management and flight crew training from December 23 through 25, 1999.

Members of the joint investigative team and their advisors gathered at Boeing/Flight Safety facilities, Long Beach, California, U.S.A., from April 3 through 6, 2000 for flight simulation tests and discussions on the probable cause of the accident.

The joint investigative team determines that the probable cause of the Korean Air flight KE 6316 accident was the flight crew's loss of altitude situational awareness resulting from an altitude clearance wrongly relayed by the first officer and the crew's overreaction with abrupt flight control inputs.

The safety issues in this report focus on flight crew performance, and pilot training. Safety recommendations concerning these issues are addressed to the KCAB and the NTSB.

1. Factual Information

1.1 History of Flight

On April 15, 1999, Korean Air cargo flight KE 6316, a McDonnell Douglas MD-11F, Korean registration HL7373, departed from runway 18 at Shanghai HongQiao International Airport, for Seoul, Korea with 2 pilots and 1 flight technician on board at 16:01:35 Beijing local time (08:01:35 UTC time). The autopilot was off 1 minute 7 seconds (at 16:02:42) after takeoff. The airplane maneuvered first to the right, and then kept level flight at approximately 200 degrees track for more than 30 seconds, and maneuvered back to the left. The crew was subsequently cleared to climb to 1,500 meters* (4,900ft) during which the airplane turned to NHW** at 900 meters (3,000ft). The airplane passed 1,310 meters at 16:04:15, the airplane suddenly executed a very rapid descent after reaching 1,370 meters (4,500ft) at 16:04:19 and then the airplane disappeared from the airport SSR screen. The airplane crashed into the ground at 16:04:35 according to Shanghai Seismic Bureau's measurement. The distance from the accident site to the airport runway is 11.6 kilometers, the site azimuth is 165 degrees from the center of the runway centerline. The site coordinate is N31° 06'00", E121° 22'16" (Crash location chart see Appendix 2) .

1.2 Injuries to Persons

Injuries	Crew	Others***	Total
Fatal	3	5	8
Serious		4	4
Minor		36	36
Total	3	45	48

1.3 Damage to Airplane

The airplane was totally destroyed by high energy impact forces and the postcrash explosion and fire.

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* Air Traffic Control (ATC) altitude assignments, within the airspace of the People's Republic of China, are issued in meters.

** NHW is the code of a Navaid fix.

*** Persons on the ground

1.4 Other Damage

The accident resulted in a huge crater on the ground and nearby temporary shacks (for the workers of the construction site) collapsed. Heavy parts and debris of the plane and cargo caused damage to nearby 32 shops and 116 resident apartments along the impact direction. The water system, city power supply and the gas supply in that area were cut off due to the accident.

1.4.1 Collapsed Wall

Along a 180-meter-long wall oriented from north to south and located in the southeast of the initial impact site, a 50-meter-long section of the wall was collapsed eastwards.

1.4.2 Building Damage

Windows and doors of the buildings, located 200 meters to the southeast of the initial impact site, on the eastside of the XinXi road south, were destroyed, metal screen doors of the shops were severely deformed inward. The north and west walls of the buildings were marked with mud globules from the crash site and other marks from debris and /or cargo.

Refer to Appendix 2 to see the wreckage and debris distribution chart

1.5 Personnel Information

1.5.1 Crew Information

The captain, the first officer, and the flight technician were certified in accordance with the Ministry of Construction and Transportation (MOCT) regulations of the Republic Korea. They had never experienced any abnormal or emergency cases in their previous flights according to the KCAB's investigation.

The Captain

The captain was born on March 29,1945, male, aged 54, held a valid Airline Transport Pilot Certificate issued by the Korean Ministry of Construction and Transport with the type ratings of F-27, B-727 and MD-11, whose Certificate number was 00628 (issued on April 22,1985). He accumulated a total of 12,898 hours of flight time. He transited to MD-11 in 1992. He had a total of 4,856 hours on MD-11. His flight time was 65 hours within last 30 days. His last simulator refresher training was conducted on October 24, 1998, in compliance with ICAO Annex 1 requirements. He had no accident record before the Shanghai accident. He had previous experience with flight routes using the metric system, and this was his second trip to Shanghai as captain.

The captain didn't habitually drink alcohol, and had no record of alcoholism or drug addiction. He did not possess any outstanding loans or have financial difficulties, nor did he have marital or personal problems that may have affected his state of mind. There are no existing factors that may suggest psychological burdens on him within 72 hours before his last flight to Shanghai. He was in good health and didn't take medicine before the accident flight. His last medical check was on December 15, 1998, in compliance with ICAO Annex 1 requirements, and his health certificate number was 983457.

The First Officer

The first officer was born on August 11,1964, male, aged 35, hired by Korean Air on April 1,1994, held a valid Commercial Pilot Certificate issued by the Korean Ministry of Construction and Transport with the type ratings of F-100 and MD-11, whose Certificate number was 02137(issued on January 29,1994). He accumulated a total of 1,826 hours of flight time. He transited to MD-11 in 1996. He had 1,152 hours on MD-11. His flight time was 74 hours within last 30 days. His last simulator refresher training was completed on October 31, 1998, in compliance with ICAO Annex 1 requirements. He had no accident record before the Shanghai accident. He had no previous experience of flying to Shanghai before the accident flight and no experience of landing at the airport with the metric system as the altitude assignment.

The first officer didn't habitually drink alcohol, and had no records of alcoholism and drug addiction. He did not possess any outstanding loans or have financial difficulties, nor did he have marital or personal problems that may have affected his state of mind. There are no existing factors that may suggest psychological burdens on him within 72 hours before his last flight to Shanghai. He was in good health and didn't take medicine before the accident flight. His last medical check was on January 13, 1999, in compliance with ICAO Annex 1 requirements, whose health certificate number was 983457.

The flight technician:

The ground mechanic, on board as the flight technician to release the fight KE6316 at Shanghai, was born on December 12, 1951, male, aged 48, held a valid Maintenance Certificate with the type ratings of DC-10, A300, B747-400, MD-11, whose Certificate number was 2068. He was hired by the Korean Air on December 4, 1978.

1.5.2 The Air Traffic Controllers

1.5.2.1 Air Traffic Control Tower Controllers

The tower controller, male, was hired by the ECA of the CAAC in Sept. 1995 and received his Air Traffic Controller Certificate issued by CAAC in Nov.1996.

The other tower controller, male, was hired by the ECA of the CAAC in July 1997 and received his Air Traffic Controller Certificate in Dec.1998.

1.5.2.2 Approach Controllers

The terminal radar approach controller, male, was hired by the ECA of the CAAC in July 1992, and received his Air Traffic Controller Certificate in Nov. 1993.

The other terminal radar approach controller, male, was hired by the ECA of the CAAC in July 1988 and received his Air Traffic Controller Certificate in Nov.1989.

1.5.3 Maintenance Personnel Information

The accident airplane was maintained by Korean Air maintenance personnel.

The ground mechanic, who released the accident MD-11 at Seoul, Korea, was born on January 14, 1955. He was hired by Korean Airlines on July 18, 1978 and received the Maintenance Mechanic License on March 29

1980 from the MOCT. The license number is 1815. He received a certificate of completion the training on MD-11 from Boeing (formerly McDonnell Douglas). He had a MD-11 type rating added to his mechanic license in March 1991.

1.6 Airplane Information

1.6.1 Airplane Status

Date of delivery: February 16, 1992
Serial Number of Delivery: No.48409
Serial Number of the Fuselage: 490
Total flight time of the fuselage: 28347:06 hours
Total flight cycle: 4463 cycles
Type of engines equipped: PW4460.

1.6.2 Maintenance Information

The airplane had a total of 224 logged discrepancies, among which were 7 operation system malfunctions, and each of them had been corrected by the maintenance personnel of Korean Air since May 1997.There had never been any horizontal stabilizer jam report since it was put into service in 1992.

The airplane had experienced a tail strike at LAX international airport, Los Angles, California, USA on May 25,1996. After that incident, the McDonnell Douglas co., Repair Station Certificate No. ML3R688L, conducted the major repair and issued a "Major Structural Repair Status" report with the FAA Form 337 attached, which is a "Major Repair and Alteration" table. The duration of the repair lasted 63 days from June3, 1996 through August 4,1996.

The airplane's last "C" check was performed on October 15, 1998 at the flight time of 25,750 hours in the Pusan Repair Company, which is a subsidiary to the Korean Air. The last "A" check was performed on March 30,1999 at the flight time of 28,107 hours in Seoul Korea.

The accident airplane was dispatched after a preflight check in Seoul on April 15,1999. There is an agreement between the Korean Air and China Eastern Airlines such that the China Eastern Airlines is the acting agent for

KAL's transit line maintenance and ground handling service in Shanghai. According to the CVR and our investigation in Shanghai, the accident crew didn't ask for any repair work before the flight departed for Seoul. The accident airplane didn't receive any special maintenance activity in Shanghai on the day of the accident.

1.6.3 Cargo information (Weight and balance)

The flight was loaded with 32 cargo pallets, 12 containers and 1 small luggage trailer, its payload was 69,122 kilograms. The maximum zero fuel weight (MAXZFW) was 204,708 kilograms, the maximum takeoff weight was (MAXTOW) 285,993 kilograms, the maximum landing weight (MAXLDW) was 213,869 kilograms according to the data provided by Korean Airlines. The calculated allowable takeoff weight of the accident flight was 225,799 kilograms, and actual takeoff weight was 206,056 kilograms on the day of the accident. The accident airplane was not overloaded.

Both flight's **load sheet** and **load planning sheet** were made by the Korean Airlines Shanghai office. The mean aerodynamic chord of the zero fuel (MACZFW) of the accident airplane was at 23.7%, the mean aerodynamic chord of the takeoff weight (MACZFW) was at 25.8%. They were all well within the limitations.

The entire 69,122 kilograms cargo was loaded by the China Easter Airlines ground handling staff, and the loading processing was under the surveillance of the Korean Air staff. They all confirmed that all the cargo compartments were fully loaded, and the cargo was arranged compactly and tightly fastened. No abnormal condition was reported during whole process of the cargo loading.

There were no dangerous articles, postage and other forbidden articles among the cargo of the accident flight according to the **cargo sheet** submitted by Korean Air Shanghai Office and the **Customs sheet** provided by the Shanghai HongQiao International Airport Customs House.

The China Eastern Airlines ground handling staff were not given any instructions to load dangerous articles onto the accident flight.

1.6.4 On board fuel information

The crew refilled the airplane in Seoul with sufficient fuel fly from Seoul to Shanghai and return to Seoul. The residual fuel on board the accident airplane in Shanghai was 22.222 tons (48,942 pounds), the fuel type was JET A1 according to the flight log book record. There was no record that indicated the airplane refilled at Shanghai HongQiao International Airport.

1.7 Meteorological Information

1.7.1 Weather Condition at Shanghai HongQiao International Airport

The weather observation for 1600 Beijing time (0800 UTC) on April 15,1999, was as follows:

Wind: 190° at 5 m/s (9.7 knots), Visibility: 7 kilometers (4.3 miles), Sky condition: cloud broken at 270 meters (885 feet), overcast at 1200 meters. Temperature: 13° C, dew point: 13° C, QNH: 1014. No adverse weather changes were reported.

According to the CVR record, the crew had received weather information from ATIS at HongQiao international Airport before takeoff, which was:

Wind 170° at 6 m/s (11.6 knots), visibility 7 kilometers (4.3 miles), ceiling 360 meters (1,181 feet), temperature 13° C, dew point 13 ° C, QNH 1015, QFE 1015, No significant weather changes were reported.

1.7.2 Light condition at the Crash site.

At the time of the crash, the light was natural daytime light.

1.8 Aids to Navigation

All the navigational aids (navaids)(such as ILS VOR/DME) installed at the HongQiao International Airport were flight checked in accordance with CAAC requirements in August 1998. All the parameters were found normal. The other navaids around Shanghai area performed properly on the day of accident. There were no malfunction reports of the navaids on the day of the accident.

At present, within Shanghai Control Area only the SSR radar is used to survey the airplanes' movements in the airspace around Shanghai. The SSR rotates at a rate of 5 seconds per revolution. It can display the position of the aircraft from above 100meters during the period of approach or display the position of the aircraft from above 500 meters during the period of takeoff. The radar system was equipped with a warning system, however it was not activated because its error tolerances were exceeded.

The members of the investigative team, together with a radar specialist from the NTSB and a radar engineer from NEC (the manufacturer of the SSR radar), made a thorough check and researched the SSR data by means of special software from NEC. They were able to get the highest point and the track of the accident airplane before its rapid descent. Available data showed that the airplane climbing to approximately 1,500 meters (4,500ft), but the last targets showed no altitude data so it was not possible to completely define the airplane trajectory using radar data. (Reference see Appendix 4)

There was no report of any radar system malfunction on the day of accident.

1.9 Communication

According to the CVR and the ATC records, the investigative team notes that the clearances were clearly and accurately issued by the controllers and no evidence of the communication facilities problems. No contributing factors were found that related to the ATC communication system.

1.10 Airport Information

The Shanghai HongQiao International Airport main runway, orienting north/south (that is runway 18L/36R), is 3400 meters (11,154 feet) long and 58 meters (190 feet) wide, and the runway surface is smooth. The airport elevation is 3 meters (10 feet) above mean sea level (MSL). The average daily number of the takeoff and landing at the airport are about 385. The obstacle free zone of the airport is in accordance with the CAAC's standards and the ICAO Annex 14 standards.

1.11 Flight Recorder

1.11.1 The accident airplane was equipped with a Universal Flight Data Recorder (UFDR), a Solid State Cockpit Voice Recorder (SSCVR) and a Quick Access Recorder (QAR). All of their cases were severely damaged and all their inner parts were separated from their cases by the impact force. After the team's thorough search of the crash site, the SSCVR circuit board and pieced tapes of UFDR and QAR were found in the vicinity of the crater and then they were sent to the NTSB laboratory in the United States. With the help of the NTSB and the manufacturer, we have got the complete contents of the CVR. Despite efforts by the NTSB and the manufacturers for more than half a year, no useful information could be retrieved from recovered potions of tapes of the UFDR and QAR.

1.11.2 The accident airplane was equipped with a Solid State Cockpit Voice Recorder(SSCVR), which contained 9 non-volatile memory chips on each side of its printed circuit board. The SSCVR provides four audio input channels for storage of consecutive information recorded in the cockpit. Though one of the chips was broken at impact, all the information in the cockpit recorded on the remaining chips was recovered with the help of the NTSB and the manufacturer.

The information contains talks between the crew, the flight crew and the ground mechanics, and the communication between the first officer and ATC controller. Additionally, CAWS and GPWS warning and alerts, and other flight deck noises were recovered.

The investigative team determines that the end of the SSCVR recording was the time of crash. The exact crash time of the accident airplane was 16:04:35(Beijing Local Time) according to the Shanghai Seismic Bureau measurement.

1.11.3 SSCVR Transcript see Appendix 5.

1.12 Wreckage and Impact Information

The accident airplane was severely fragmented due to the extreme impact force, and the postexplosion and postfire. Wreckage and debris were distributed and scattered in a fan shape pattern extending for approximately 2 kilometers from the initial impact site, and in the direction the airplane was traveling at the time of impact. (Wreckage distribution chart see Appendix 3).

The investigation indicates that the four landing gears were in their stowed positions. The impact scars left by the No.1 and No.3 engines indicated that the airplane impacted the terrain at about 20-40 degrees nosedown. The ground scars indicated that the wings were at the wings-level attitude. The speed at impact was 398 Knots according to the indication on the standby altitude/airspeed indicator found at the crash site. The mechanism of the standby airspeed indicator indication was totally jammed.

1.12.1 Ground Impact Angle

The accident airplane impacted the ground at the angle of between 20-40 degrees according to the ground impact scars at the crash site.

1.12.2 Wing

1.12.2.1 Spoilers (L/H Wing)

The No. 1 spoiler was recovered in three pieces separated on each side of the actuator. The actuator was found in the stowed (closed) position. There was no apparent fire damage.

The No. 2 spoiler was found in two pieces, separated from the actuator. The actuator was found in the stowed (closed) position. There was no apparent fire damage.

The No. 3 spoiler was found complete with its actuator still mounted to a section of the wing rear spar. The actuator was found in the stowed (closed) position. No apparent fire damage.

The No. 4 spoiler was partially recovered (approximately one half-span). The actuator was found in the stowed (closed) position. There was no apparent fire damage.

The No. 5 spoiler was recovered in one piece (complete). The actuator was found in the stowed (closed) position. There was no apparent fire damage.

1.12.2.2 Spoilers (R/H Wing)

The No. 1 spoiler was recovered in three pieces, separated on each side of the actuator. The actuator was found in the stowed (closed) position. There was no apparent fire damage.

The No. 2 spoiler was found in three pieces, separated from its actuator. The actuator was found in the stowed (closed) position. The spoiler was found with moderate fire damage.

The No. 3 spoiler was partially recovered (approximately one half span) and was still attached to a portion of the wing rear spar. The actuator was found in the stowed (closed) position. There was no apparent fire damage.

The No. 4 spoiler was partially recovered (approximately two thirds span) with the actuator still attached to a portion of the rear spar. The actuator was found in the stowed (closed) position. Moderate fire damage was found on it.

The No. 5 spoiler was recovered in several pieces with the actuator found in the stowed (closed) position. There was no apparent fire damage.

1.12.2.3 Winglets

The left and right hand wing upper winglets were recovered with no apparent fire damage.

1.12.2.4 Wing Leading Edge Slats

The No. 1 (L/H) slat [P/N ARB 2671-1 (Support)] was recovered with a witness mark on the lower surface of the slat track. The witness mark was measured 35.5 inches from the aft end of the track, corresponding to the retracted position of the No. 1 slat.

The No. 7 (L/H) outboard slat [P/N ARB 7238-1 (track)] was recovered with a witness mark on the upper side roller surface. The witness mark measured 15.5 inches from the aft end of the track, corresponding to its retracted position.

1.12.2.5 Outboard Ailerons

The L/H Wing outboard aileron was not recognized in the aircraft wreckage. The aileron actuator with broken hinge was recovered. The actuator measured approximately 5.0 inches from the aft body of the actuator to the center of its hinge bolt. (Note: Aileron manufactured from carbon fiber composite materials). Carbon fiber material (burned fibers /fabric) were found throughout the aircraft wreckage. No aileron balance weights were recovered.

The R/H Wing outboard aileron was partially recovered (one small section) with heavy fire damage. The aileron actuator with hinge was recovered. The actuator measured 6.0 inches from the aft body of the actuator to the center of its hinge bolt. Three balance weight support brackets were also recovered. No aileron balance weights were recovered.

1.12.2.6 Inboard Ailerons

The L/H inboard aileron was recovered in several pieces with the actuator attached. The actuator measured 10.75 inches from the aft body of the actuator to the center of its hinge bolt. The aileron was found with moderate fire damage.

The R/H inboard aileron was recovered in five (5) pieces with the actuator attached and heavy fire damage throughout. The actuator measured 10.75 inches from the aft body of the actuator to the center of its hinge bolt.

1.12.2.7 Outboard Flaps

The L/H outboard flap was recovered in five (5) large pieces. The outboard hinge with actuator was recovered. The outboard actuator outer cylinder was cracked open. The outboard actuator measured 4.81 inches from the aft body of the actuator to the center of its hinge bolt. The inboard hinge with actuator was recovered. The inboard actuator measured 6.75 inches from the aft body of the actuator to the center of its hinge bolt. The flap was found to have minor fire damage.

The R/H outboard flap was recovered. Approximately two thirds of the flap exhibited heavy fire damage. Both hinges with actuators were recovered.

Both actuator inner cylinder lug ends were broken off at their hinge attachment points with the cylinders in their retracted position.

1.12.2.8 Inboard Flaps

The L/H inboard flap was recovered in two large pieces with moderate fire damage. The outboard hinge fitting was not found. However, the inboard hinge drive mechanism with attached actuator was recovered. The inboard actuator measured 5.25 inches from the aft body of the actuator to the center of its hinge bolt. The outboard hinge actuator was also recovered and measured 4.7 inches from the aft body of the actuator to the center of its hinge bolt.

The R/H inboard flap was recovered in four (4) large pieces with moderate fire damage. The outboard hinge fitting was not found. However, the inboard hinge drive mechanism with attached actuator was recovered. The inboard actuator measured 6.60 inches from the aft body of the actuator to the center of its hinge bolt. The outboard hinge actuator was also recovered and measured 4.8 inches from the aft body of the actuator to the center of its hinge bolt.

1.12.3 Empennage

1.12.3.1 Rudder(s)

The upper forward rudder section was recovered in four (4) pieces, including the upper balance weight. The upper forward rudder actuator was recovered and measured 7.13 inches from the aft body of the actuator to the center of its hinge bolt. No fire damage was present.

The upper aft rudder section was recovered in three (3) pieces with no fire damage.

The lower forward rudder section was recovered in one (1) piece. The lower rudder actuator was recovered and measured 4.25 inches from the aft body of the actuator to the center of its hinge bolt. Minor fire damage was present on the lower forward rudder section outer skins.

The lower aft rudder section was recovered in one (1) piece with moderate to heavy external fire damage.

1.12.3.2 Elevators

1.12.3.2.1 Outboard Elevators

L/H Outboard Elevator

Approximately 32 inches (span) of the outboard elevator (outboard end) was recovered with parts of its balance weight present. Another section (approximately 36 inches in span) with a hinge and damaged actuator was found. The actuator measured 6.50 inches from the aft body of the actuator to the center of its hinge bolt. Three (3) intermediate hinges were also found. No apparent fire damage to the outboard elevator was found.

R/H Outboard Elevator

Approximately 36inches (span) of the outboard elevator (outboard end) was recovered with its balance weight. Four (4) hinges were recovered [i.e. one actuator hinge and three (3) intermediate hinges]. The actuator measured 7.0" from the aft body of the actuator to the center of its hinge bolt. No apparent fire damage to the outboard elevator was noted.

1.12.3.2.2 Inboard Elevators

L/H Inboard Elevator

The L/H inboard elevator was found in two (2) pieces. One section measured 45 inches (span) and the other measured 30 inches (span) with an actuator attached. The actuator measured 7.13 inches from the aft body of the actuator to the center of its hinge bolt. The 30 inches section of elevator exhibited moderate fire damage. The L/H detachable elevator was also recovered with no apparent fire damage.

R/H Inboard Elevator

The R/H inboard elevator was found in one (1) piece which measured 30 inches (span). The elevator actuator was found attached and measured 7.5 inches from the aft body of the actuator to the center of its hinge bolt. No fire damage present. The R/H detachable elevator was not recovered.

1.12.3.3 Horizontal Stabilizer

Horizontal Stabilizer Jackscrew Drive Mechanism

A 26 inch section of the L/H jackscrew was recovered with its chain drive assembly broken off and missing. The jackscrew drive nut was found secure to the jackscrew and measured 10.25 inches from the lower edge of the drive nut to the centerline of the attachments for its base mount. Sixteen (16) inches of the upper end of the jackscrew was found attached to the L/H horizontal stabilizer pivot bulkhead. No fire damage was present on the pivot bulkhead structure.

A 31 inch section of the R/H jackscrew was recovered with its chain drive assembly and drive nut secured. The jackscrew drive nut measured 10.25 inches from the lower edge of the drive nut to the centerline of the attachments for its base mount. Seven (7) inches of the upper end of the jackscrew was found attached to the R/H horizontal stabilizer pivot bulkhead. No fire damage was present on the pivot bulkhead structure.

The position of the left and right hand jackscrew drive nut assemblies corresponds to an aircraft nose up attitude of approximately 0.65°.

The jackscrew chain drive assembly was recovered intact.

1.12.4 Landing Gear

The left and right main landing gear, center gear, and nose landing gear were all recovered. The left and right main landing gear forward gear support (shear) pins were found intact. Note: these support pins are designed to shear under high gear drag loads to prevent the rupture of the nearby wing fuel tanks. The nose landing gear door actuator was found intact and in the retracted position. There was no evidence of any fire or explosion in the wheel well area to include the landing gear tires and associated brakes.

The landing gears were determined to be in their stowed position at the time of the crash.

1.12.5 Fuselage

1.12.5.1 Fuselage Doors

All cargo door latches that were recovered were found in their latched position. The forward upper cargo door was found with approximately one half (1/2) of its structure attached to the upper hinge. The lower center cargo door was found complete and attached to its surrounding structure with all its latches in their latched position. The aft bulk cargo door was found complete with its surrounding structure with all its latches intact and in their latched position. The lower forward cargo door was found in many pieces. Several cargo door detached latches were found in their latched positions.

1.12.5.2 Forward Upper Cargo Net

The forward upper cargo net was found intact and attached to its fuselage attachment fittings which were found torn away from their surrounding fuselage structure (i.e. supports).

1.12.5.3 Airframe Structure /Fire Damage

Approximately 20% of the fuselage exhibited fire damage. Fire damage was noted on the lower surfaces of the number five (5) section of fuselage, fire damage was also noted on portions of the (E) and (J) sections, and various other unidentifiable sections of fuselage structure. Each section which exhibited fire damage showed signs of external damage. Internal fire damage was noted on the lower section of the (J) barrel between the aft pressure bulkhead and the APU compartment bulkhead.

Fire damage was noted on the horizontal stabilizer center box section [aft one third (1/3)] including the left and right hand pivot bulkheads and portions of the rear spar. Fire damage was prevalent on the center section inner lower surfaces.

Fire damage was noted aft of the horizontal stabilizer center box structure on the tail cone bulkhead.

Fire damage was noted forward of the horizontal stabilizer center box structure on the lower one fifth (1/5) of the aft pressure buiкhead. Portions of the aft pressure bulkhead, including the web and its circumferential fuselage attachment chord were found in several small pieces.

1.12.5.4 Fuselage Nose

No major sections of the windshield and /or surrounding structure was recovered. However, many small pieces of cockpit upper nose structure were identified with no indication of fire damage. Portions of the circuit breaker panels and wiring were found with no indication of fire damage. The back of one flight crew seat cushion and various pieces of crew seat frame, including shoulder harness inertia reel were found with no indication of fire damage.

1.12.6 Powerplant

The airplane, a Korean Air MD-11F, was equipped with Pratt & Whitney PW4460 engines. The No. 1 and 3 (left and right) engines were buried in the ground at the initial point of impact and the No. 2 (center) engine was found amidst the debris field on a street 230 meters downrange from the point of impact.

The No. 1 and 3 forward engine mounts were found attached to their associated pylons and were bent aft. The No. 2 engine mounts were found attached to the engine.

The examination of the engines showed very similar damage patterns. The fans had separated from the engines during the accident sequence. None of the engines had any indication of an uncontained disk or blade separation, case rupture, or inflight fire.

The No. 1 and 3 engines were in virtually identical condition. The No. 1 and 3 engine fan disks were missing most of the fan blades. However, the fan blades that remained in place in the blade slots were primarily bent towards the direction of rotor rotation, which is indicative of an engine that was at a low power level with low rotational speed. The No. 1 and 3 engine fan containment case rubstrips did not have any circumferential grooving from the fan blade tips, which is indicative of an engine that was operating at a low rotational speed. The No. 1 and 3 engine low pressure turbine shafts were both fractured just forward of the 9^{th} stage compressor disk, but also had axial fractures extending rearward from the primary fracture, which can only occur if there is little to no rotational energy in the low pressure turbine shaft. If the engine was at a high power setting that would have required a great deal of torque to drive the fan and low pressure compressor, the fracture in the shaft would have been in a spiral pattern. The low pressure turbine blades in the No. 1 and 3 engines were fractured adjacent to the blade root platform. However, the fractured ends of the blades were full lengths and most were straight with a few that were bent slightly. The 6th stage turbine blades in the No. 2 engine were all full length except for those that were broken from where the turbine exhaust case was crushed inward. The damage to the low pressure turbine blades is indicative of an engine that is operating at a low rotational speed where all of the rotational energy can be absorbed by the fan during the initial impact.

The examination of a fuel nozzle from the No. 3 engine and the combustor liners, the 1st stage turbine vanes and blades, and the low pressure turbine blades from the three engines did not reveal any metal spatter on the surfaces. If one of the engines had experienced an internal failure before impact, the grinding process of the blades and vanes would have reduced any liberated metallic objects in the gas path to small particles that would have adhered to any hot objects downstream in the gaspath. The absence of any metal spatter on the downstream parts indicates that the engines did not experience an inflight failure before impact.

The No.2 and No3. Engines' EECs were read out and indicated that the major parameters were normal with on indication of a power loss.

The examination of the thrust reverser actuators showed the drive mechanism was at the forward end, which is the stowed position. In addition, the thrust reverser cascades that were recovered were not packed with mud further indicating the reversers were stowed at the time of impact.

The crew didn't mentioned any engine failure during the accident flight according to the CVR, furthermore they didn't take any action to return to the departure airport.

We conclude that the engines were operating at a low rotational speeds at the time of impact. There was no indication that any of the engines had experienced a malfunction or failure before impact. The engines were not causal to the crash of the airplane.

1.12.7 The hydraulic system

After checking all the hydraulic system among the wreckage, analyzing the CVR and SSR plot, the investigative team didn't find any evidence of hydraulic system failure.

1.12.8 Other information

All external tips of the wings, horizontal tail and rudder were recovered from the crash site. All flight control actuators were recovered and their respective measurements recorded. However, these actuator measurements may not accurately reflect the true position of the respective flight control surfaces due to the damage sustained at the time of the crash and /or during the recovery process. The majority of the fire damage witnessed was noted on exterior surfaces indicating post crash fire damage.

1.12.9 The distribution of the wreckage

The accident airplane debris and cargo goods were scattered on the ground and the roofs of buildings to the southeast of the impact site within the fan shaped area. No debris and cargo goods were found in the other directions from the impact site.

1.13 The Medical and Pathological Information

The experts of the security group used DNA technology to analyze all the remains of the crewmembers found in the vicinity of the crash site. The result indicated that there were no other persons on board the accident airplane other than the three assigned crewmembers.

1.14 Fire

36 fire engines were sent to the crash site immediately after the accident, and the first fire engine reached the site within 20 minutes. The fire caused by impact was put out by foam at 16:59(Beijing Local Time).

1.15 Survival Aspects

After the accident, armed policemen, the local authority and the staff from ECA of CAAC arrived at the site to locate and assist the victims. No crew member survived and no intact crew member bodies were found. 5 persons on the ground suffered fatal injuries. The injured persons on the ground were immediately send to nearby hospitals for emergency treatment.

1.16 The technical measures used for investigation

1.16.1 Sabotage Examinations

The investigators performed a complete survey along the flight path of the accident airplane. No components or cargo goods of the accident airplane were found before the point of impact. No witnesses claimed that they had seen the accident airplane exploding in the air. The distribution of the scattered cargo goods and damaged buildings indicated that the airplane was intact at the time of impact. All damage to the airplane was the result of impact force and postimpact explosion and postfire.

The security group of the investigative team picked 13 different specimens from the wreckage and sent them to the laboratory of the National Public Security Bureau. Their experts performed gaseous chromatography, liquid chromatography, mass chromatography, electronic microscope scanning/energy chromatography and other chemical analytical tests on each specimen. There was no evidence of explosives found in any of the specimens.

1.16.2 Hazardous Materials

Shanghai Nuclei Salvage Station checked all the 17 wreckage piles and didn't find any radioactive materials or any other harmful materials.

The investigative team found no evidence of a bomb, or other flammables, hazardous materials, or corrosives that could have contributed to this accident.

1.17 Test and Research

1.17.1 CVR Spectrum Analysis

The investigative team notes that there was not any abnormal sound which can be heard on the CVR, and the rattling sounds did not correspond to the stick shaker stall-warning according to the CVR spectrum analysis done by the NTSB.

The rattling sounds recorded on the cockpit area microphone channel of the CVR at 16:04:45 and 16:04:50 were examined in an attempt to determine the source of the rattling sound. The spectrum analysis of the sounds made by the NTSB indicates that the pairs of sounds are repeating at approximately 10-Hertz over the 5-second period. This rate does not correspond to the stick shaker stall-warning rate, but it is more representative of a rattling dash or glare shield panel in the cockpit of the airplane (full report see Appendix).

1.17.2 Honeywell Analysis of GPWS Warnings

The investigative team sent the last 10 second portion of CVR retrieval to the GPWS manufacturer, Honeywell. The GPWS manufacturer analysis indicated that the accident airplane's descent rate at impact was greater than 30,000 ft/m (full report on the analysis see Appendix 7).

1.17.3 Analysis of Recorded SSR Mode C Altitude Data

The investigative team found that the accident airplane had climbed to approximately 1,370 meters (4,500 feet) at its last recorded radar data point prior to impact, and the elapsed time from the last recorded radar data point to ground impact was approximately 16 seconds. The average descent rate required to travel from 1,370 meters (4,500 feet) to ground level (approximately 10 feet MSL) in 16 seconds is approximately 16,875 ft/minute.

1.18 Follow-up Examinations of the Flight Control Actuators

1.18.1 Elevator Actuators

The elevator actuators were forwarded to the actuator manufacturer in the United States for teardown inspection.

Contaminants were found primarily at or upstream of the manifold inlet screens and main filters. Contamination of the fluid downstream of the screens and filters consisted of a fine metal "dust" with some larger particles found in the main control valves. The participants in the examinations agreed that the contaminants within the actuators did not appear to affect normal operation but that the quantity of contaminants trapped in the inlet screens could have impeded hydraulic fluid flow.

Witness marks from the actuator internals corresponded to the following estimated elevator deflections: 1) left inboard—1.44 degrees trailing edge up (TEU) (actuator length 18.294 inches); 2) right inboard—0.68 degrees TEU (actuator length 18.21 inches); 3) left outboard—1.03 degrees trailing edge down (TED) (actuator length 14.74 inches); and 4) right outboard—2.54 degrees TEU (actuator length 15.11 inches).

1.18.2 Aileron Actuators

The aileron actuators were returned to the manufacturer in the United States for teardown examination. All actuators were noted to have received substantial damage, consistent with ground impact, and the manifold assemblies were either separated from the cylinder assemblies or missing, which precluded functional testing. Only the left outboard aileron actuator evidenced internal circumferential impact "witness" marks, which corresponded to a 0 degree or neutral deflection (actuator length 12.6 inches). The other actuators were measured "as is" and the estimated corresponding deflections were: 1) inboard S/N 0959 (position unknown)—6.3 degrees TED (actuator length 21.4 inches); 2) inboard S/N unknown (position unknown)—18 degrees TED (actuator length 22.8 inches); and 3) right outboard—20.2 degrees TED (actuator length 14.5 inches).

Corrosion was observed in and/or on all the actuators, but appears to be consistent with post-impact exposure to moisture. Some contaminants, which appeared to be soil, were found on or in the actuators or inlet screens. The main hydraulic filter for the left outboard actuator was clear.

No evidence of pre-impact malfunction or jamming was found.

1.18.3 Rudder Actuators

The rudder actuators were returned to the manufacturer in the United States for teardown examination. The actuators were noted to have received substantial damage consistent with ground impact and the manifold assemblies were separated from the cylinder assemblies. The inlet screens from both actuators were partially obstructed by a substance resembling soil. The main hydraulic filter from the upper actuator contained a moderate amount of fine metallic particles. The servo slide cavity from both actuators contained a substance resembling water and/or water and silt. The lower rudder actuator had a circumferential impact mark corresponding to a rudder deflection of 8.8 degrees trailing edge right (TER) (actuator length 16.0 inches); the upper actuator did not have an impact mark. The measured "as is" upper actuator length corresponded to an estimated deflection of 24 degrees trailing edge left (TEL) (actuator length 12.2 inches).

No evidence of pre-impact malfunction or jamming was found.

The contaminants within the actuators were further examined. The contaminants consisted primarily of metal dust, tan particles and dirt. Nothing unusual was found with them. Detail information of the contaminants examination is in the Appendix 11.

2. Analysis

2.1 General

The three Korean Air flight KE6316 crewmember (two pilots and one flight technician) were properly certified both in their qualifications and health status by the Korean Civil Aviation Bureau in compliance with the Annex 1 of the International Civil Aviation Organization Convention. The result of the investigation indicates that there no was evidence of any medical factors that may have affected the flight crew's performance during the flight.

The Korean Airlines flight KE6316 accident airplane was properly certificated, maintained and operated in accordance with applicable the KCAB and ICAO standards and Korean Airlines procedures.

The result of investigation indicates that no maintenance requirement reports were generated by the flight crew on the flight from Seoul, Korea, to Shanghai, China and the flight to Shanghai was uneventful.

The weight and balance of the accident airplane was well within the loading and balance requirements of the airplane.

There are no evidences show that the airplane sustained preimpact structure damage. The accident crew didn't report any malfunction of the airplane after takeoff.

The accident airplane was under the control of the crew throughout the accident flight. The three engines didn't lose power or malfunction during the flight.

The readouts of both No 2 and 3 EEC indicated that the engines' major parameters were normal during the flight. There were no evidence indicated that the power of engines were lost during the flight.

The ATC controllers involved with the flight hold appropriate certificates issued by the CAAC in accordance with the controller qualification requirements and their qualification as full-performance level controllers. The controllers issued ATC instructions correctly. ATC radar, communications and navaids equipment were found to be functioning properly on the day of accident.

The designs of runway 18 SID for HongQiao international Airport and the aerodrome free zone are in compliance with the standard guidance of the ICAO Annex 14.

The investigative team didn't find any evidence that indicated that the accident was caused by the airplane malfunction.

2.2 Flight control system

Flight control checks were performed by the flight crew after engine start with no discrepancies noted.

If it is assumed that the witness marks indicate elevator actuator position at initial impact, then it appears that the elevators were deflected nearly symmetrically, with no elevator panels deflected fully TEU or TED. Therefore, it appears unlikely that there were any jammed elevators at the time of initial impact.

The only aileron actuator with an apparent initial impact witness mark was the left outboard aileron actuator. The mark corresponded to an aileron deflection of 0 degrees, which is consistent with witness statements of the aircraft impacting the ground at a wings-level attitude. Otherwise, the aileron and rudder actuator examinations for initial impact positions appear to be inconclusive.

The investigative team did not find any evidence that indicated that the accident was caused by any malfunction of the airplane's systems or structures.

2.3 Pilot training

The Seoul-Shanghai route is the only air route, operated by Korean Air, which utilizes the metric system for ATC altitude clearances. The captain had flown into Shanghai only once before, and the first officer had never been to Shanghai prior to the accident flight. Korean Air requires its pilots to watch a video tape about the Shanghai HongQiao International

Airport and converting meters to feet before flying to Shanghai. The captain had watched the video on January 30, 1999, on the day of his first flight to Shanghai. The first officer watched the video on the morning of April 15, 1999, which was the day of the accident.

The CVR transcript illustrates that the crew referred to altitude clearances in both "meters" (some of the time) and "feet" (some of the time). They did not choose to use only one unit, or the other, for altitude clearances to avoid confusion. The CVR transcript clearly illustrates that the flight crew was in a nearly continuous state of confusion regarding their altitude clearances. This was not standard operating procedure.

The investigative team notes that the crew had not followed Korean Air's flight operation manual, as approved by the KCAB, in some areas during the accident flight.

The investigative team notes that the crew was not well prepared for the route from Seoul to Shanghai and back, and didn't follow standard flight operation procedures on their mission.

2.4 Weather factors on departure

The weather prevailing on the accident day was within the capability of the airplane and the flight crew. A review of the meteorological report indicates that there was no adverse weather affecting the flight safety along the flight route. The ATC controllers didn't receive any abnormal weather reports from the pilots operating in the vicinity of Shanghai.

2.5 Standard Instrument Departure(SID) Procedure

The published SID procedure for runway 18 at Shanghai HongQiao International Airport indicates that the airplanes are expected to maintain the runway heading until 6 DME from SHA (the airport fix) via WB (NDB), at or above 300 meters (900 ft) turn left to the waypoint of NHW after taking off, and then climb to 1,500 meters (4,900 ft) at NHW. The ATC will give the crew left turn departure instructions to NHW if there is no conflict condition around the vicinity of Shanghai airport. (For more information on the SID for runway 18 at HongQiao International Airport, see Appendix 4).

Note: SHA and WB are the codes of the navaids of the waypoint.

2.6 Simulator flight test and its results

Members of the investigative team and advisors from the CAAC, the NTSB and the KCAB, gathered at Boeing/Flight Safety, Long Beach, California, U.S.A., from April 3 through 6, 2000 for the simulator flight test based on data recovered from the CVR and SSR plot. More than one hundred flight simulation scenarios were performed, which provided valuable data for analysis and determination of the probable causes of the accident. With an emphasis on respect for science, and utilizing realistic principles, the investigators engaged in fruitful discussions and analyses, which were used to develop the conclusion, findings, and probable cause contained in this report.

2.6.1 CAWS Altitude Alerting

The Central Aural Warning System will issue an "Altitude" voice alert when the airplane is approaching a preselected altitude. The alert will sound 1,000ft before the preselected altitude in a normal flight condition. If the rate of closure on the preselected altitude is such that more than 1.1g would be required to capture the selected altitude, a second "Altitude" alert will sound once the airplane is within 1,000ft of the preselected altitude.

2.6.2 CAWS Altitude Alert 8 Seconds Prior to Impact

The evidence of last aural "Altitude" alert approximately 8 seconds prior to impact, in combination with the results of the simulator flight tests and the "Altitude" voice alert principle, leads the investigative team to believe that the last recorded "Altitude" alert was most likely issued while the accident airplane was descending through 2,500 feet. This would be consistent with the accident crew having preselected 1,500 feet on the FCP window. Therefor, we can exclude the possibility that the crew still armed the altitude at 4,900ft.

2.6. 3 Different status result in different warnings

If the pitch angle exceeded 40 degrees, there would be no GPWS warning, based on the simulator tests and information from the radar altimeter manufacturer, the GPWS may not activate if the airplane pitch down angle is greater than 40 degrees, since the radar altimeter may be sending invalid data to the GPWS and CAWS under these conditions. But if the pitch down angle was close or less than 20 degrees, The CAWS will issue an aural alert like "Approaching Minimums" or "1,000" feet. Therefore the different warning will be issued according to the different pitch angle and descent rate.

2.6.4 The elevator jam

If the elevator was jammed during the climb, the airplane should maintain a state of climb rather than pitch down. If the elevator was jammed in a pitch down attitude, the crew should have trimmed the stabilizer backward in an attempt to recover.

2.6.5 Horizontal Stabilizer trim

If the accident airplane was at 250 knots in a clean configuration during the level flight, the horizontal stabilizers setting would be 2.4 degrees ANU. Just before the airplane entered into a pitch down attitude, the slats might have been retracted and the climb initiated, but the speed might not have accelerated to 250 knots. The first officer alerted the captain to the pitch attitude during its climb to 4,900ft. The crew overtrimmed the horizontal stabilizer at the beginning of the pitch-over. The crew might have set the horizontal stabilizer at greater than 4 degrees ANU during the period from level flight at 900 meters (3,00ft) to climb on the basis of flight simulator flight test and above analysis. The horizontal stabilizer warning principle indicates that the "Stabilizer Motion" warning and tones from CAWS will initiate after 2.0 degrees of continuous movement at the speed below 250 knots and the stabilizer trims at a rate of 0.5 degrees/sec or if the speed is above 250 knots the stabilizer trims at a rate of 0.2 degrees /sec. The CVR transcript indicates that the stabilizer motion warning and tones lasted 10 seconds, which means if the crew trim the stabilizer backwards the setting of the horizontal stabilizer would be 8 degrees at the time of crash rather than 0.65 degree. On the basis of the horizontal stabilizer at greater than 4 degree ANU before climb to 4,900 ft to 0.65 degree at the time of crash, the investigative team confirms that the crew trimmed the stabilizer continuously forward in order to attempt a quick descent to a lower altitude and counteract the control column force at the descent initiation and during descending. The captain had got second wrong altitude information from the first officer at 16:04:20, which is 5 seconds prior to the first aural "Stabilizer Motion" alert and the crew had initiated the pitch trim, which decreased the stabilizers' ANU to less than 2 degrees (the speed was smaller than 250 knots). Within the 10 seconds between the first last "Stabilizer motion" aural alert initiation and the last "Stabilizer motion" aural alert at 16:04:30, the horizontal stabilizers had been further decreased for about 1 to 2 degrees, during which the speed was greater than 250 knots. The crew might trim the stabilizers backward while trying to pull the control column back at the last seconds before the crash. The back trim of the stabilizers might result in an increase of the stabilizers' ANU to 0.65 degree.

2.6.6 The elevator out of control

If the elevators were out of control, the pitch down angle will be between 70-90 degrees, which was not consistent with what was found at the crash site. Therefore, there is no such a possibility that the accident was caused by elevators' malfunction.

2.6.7 Horizontal Stabilizer Jammed Full Nose Down

If the horizontal stabilizer were jammed at the extreme position of full trailing edge down, the forces created by nose up elevator input can overcome the stabilizer-generated nose down forces by the pilot pulling the control column to its most nose up position. That means that the elevators can overpower the out-of-trim stabilizer. Therefore the investigative team excludes the possibility that the horizontal stabilizers jammed at the extreme position which caused the airplane to dive.

2.6.8 The elevator and horizontal stabilizer operation

The horizontal stabilizer and the elevator can be operated in different directions at the same time, which means if the horizontal stabilizers were out of control no matter in whatever conditions and made the airplane nose down, the pilot can still control the airplane to nose up by using the elevators. Even if the airplane pitched down in case of the horizontal stabilizer out of control, the pilot can still override the electrical trim system with a pair of LONG TRIM suitcase style handles on the captain's side of the forward pedestal, or use the control column to operate the elevators to nose up.

2.6.9 Recovery from different altitudes

If the horizontal stabilizers were in their most trailing edge down position, and caused the airplane to dive from 4,500 ft with a nose down angle of about 35 degrees, and if the elevators works properly (or even with one side is jammed), the pilot can still recover the airplane if he starts to pull up at 2,000 ft. If he initiates recovery at 1,500 ft, however, in most cases he will fail the recover due to lack of sufficient altitude, which is quite similar to the actual accident in terms of the crash time, pitch angle, indicated airspeed at impact and GPWS warnings.

2.6.10 Throttles position

The crew should increase power to recover from diving instead of allowing the autothrottles to go to idle power, if the pitch control system was jammed or out of control in a nose down direction.

2.6.11 Stall

The flight simulation test indicated that the accident didn't result from an aerodynamic stall.

2.6.12 Comparison between Simulator test and Recorded information

The following data are the results of comparison between the simulator flight test and KE6316 CVR recording:

Source Of info.	Total flight time	Time Between The highest Point to the Crash point	The Indicated Airspeed At impact	The Pitch angle At impact	The horizontal Stabilizer setting at Impact	The Warnings From the CAWS and GPWS
KE 6316	3 (s*)	16(s*)	398knots	About 20--40°	0.6°	"Altitude"alter once "terrain, terrain" alter once. "oh oh, pullup, pull up" twice
Simulat or	3(s*) 04	18(s*)	394knots	About 25°	0.7°	"Altitude" alter once, "terrain, terrain" once "oh oh, pull up, pull up" three times

s*: second

Note:

1. All the data put into the simulator was the same or as close to those which the accident airplane had experienced in terms of the flight conditions, meteorological parameters, weight and balance, etc. except for the wind above ground level (due to the limitations of the simulator).

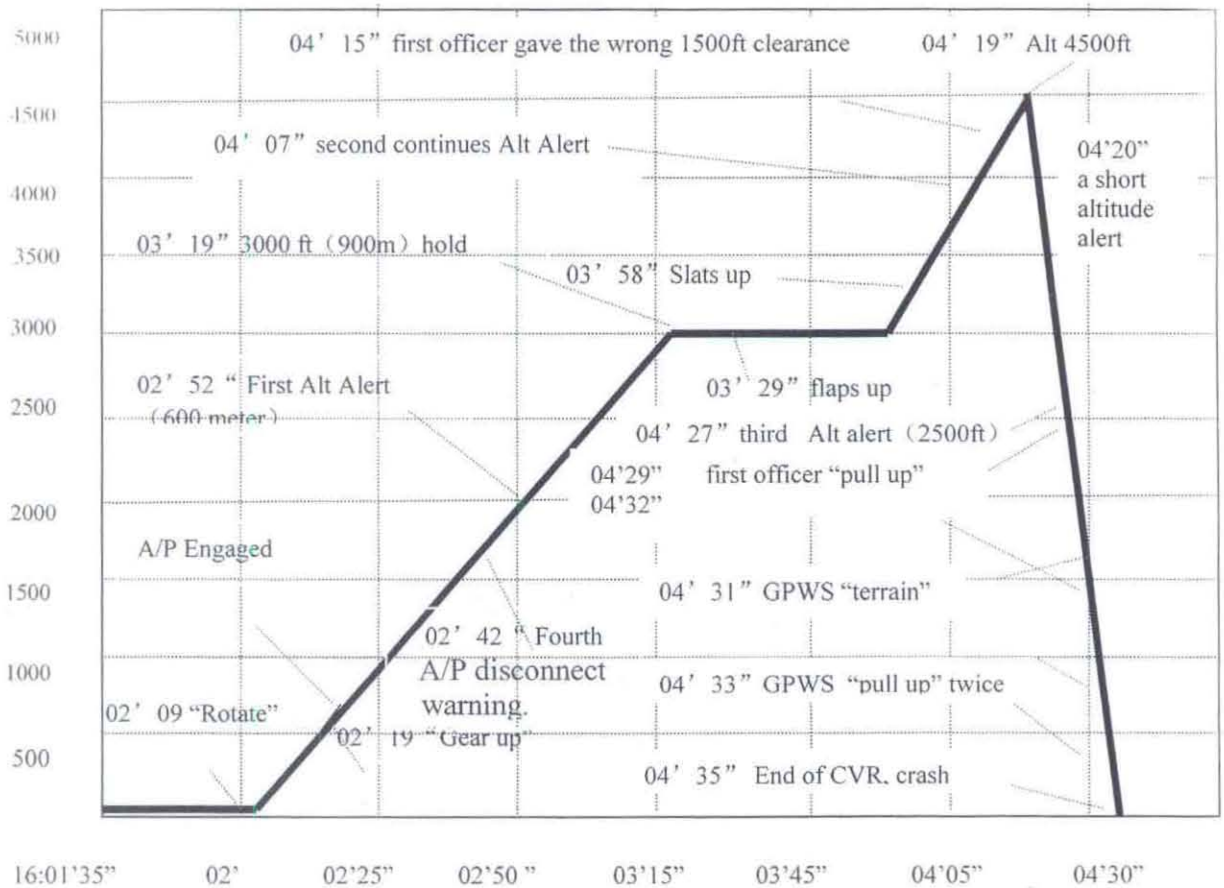
2. If the aircraft was nose down at a pitch attitude of 35 degrees, and when the pilot starts the recovery at 1,500 ft above ground level, he was unable to recover by pulling back the control column to its full nose up position.

3. The simulator is a training device qualified for specific training scenarios and there may be certain differences beyond the normal envelope. It can correctly demonstrate the actual flight situation when the scenario is within the normal envelop.

The results of the simulator flight tests were based on the radar and the CVR data and other data from the investigation, but lack of data from the QAR and the UFDR. The purpose for the simulator flight test was to duplicate the accident flight, which can provide assistant information for understanding the probable cause of the accident.

s*: second

2.7 Accident Flight profile



2.8 Crew Performance Analysis

Before takeoff

Time	Reference: CVR and Radar Plot	Analyses
15:44:30	Capt. "okay brake Released"	Push back from parking point No.911.
15:46:27	Int. Capt. "Roger, start engine 3"	The crew initiated the engine.

15:48:05	Radio: First officer: "Korean Air six three one six clear to destination ah flight planned route maintain flight level two nine zero departure frequency one nineteen seven five. Squawk six three one six after takeoff turn left to November Hotel Whiskey initially nine thous- nine hundred meters "	The crew had received the departure clearance. The first officer reads back their departure clearance.
15:49:03	Capt. "900 meter"	The captain was not sure about the 900 meters initial altitude clearance.
15:49:07	Capt. "isn't that 1,000 ft?"	The captain thought that the initial altitude was 1,000ft.
15:50:05	Capt. "is it nine hundred Meters?"	The captain doubtful about the 900 meters initial altitude
15:50:10	First officer: "yeah nine hundred feet, we don't need this and it is radar vector, you may go to November Hotel Whiskey just right after Takeoff ,they didn't give me a SID "	The first officer confused the initial altitude units by mistaking the meter for feet. When the captain was ready to input the SID for runway 18 to FMS, the first officer might give captain incorrect message for the FMS entry.
15:50:23	First officer: "let's change it to meter; nine hundred meter nine hundred meter, we need to head to November Hotel Whiskey right after climb to four hundred feet. squawk six three one six"	The first officer felt that the ATC clearance was meter, so possibly he changed the altitude setting to meter on FCP.

15:51:46	ATC controller: "Korean Air six three one six taxi via kilo seven tango zero for runway one eight."	The flight was cleared to taxi to runway 18.
15:53:59	The captain: "turn on the direct after airborne, let's make it turn at four hundred ten"	The captain accepted the first officer's clearance of direct turn after takeoff, and prepared for it.(the normal procedure is that the left turn is only given by the ATC)
16:01:28	ATC controller: "Korean Air six three one six clear for takeoff." The first officer: "clear for takeoff Korean Air six three one six."	The crew received the Clearance for takeoff.

The accident crew talked about a high brake temperature reading, and the other things like the HongQiao Airport and other airplanes parking on the apron during their taxiing, but didn't mention any specific malfunctions on the accident airplane.

The investigative team notes that the accident crew had three problems among the crew according to the CVR:

1.The crew was not quite clear about the departure altitude after takeoff, and they were not clear about the altitude conceptually in terms of meter or feet.

2.The first officer thought that their departure was radar vector after takeoff, while the captain thought that they could fly directly to NHW at 410ft after takeoff .The normal procedure is that the airplane can fly direct to NWH only after receiving the ATC permission if there is no conflict traffic.

3.The crew didn't conduct standard takeoff brief before takeoff according to the CVR information. The investigative team checked the accident captain's technical check record in Korean Air headquarters, which indicated that the captain's briefing including SID was not satisfactory in his simulator training in March 1998.

We acknowledge that the crew was not clear about the departure altitude and no takeoff briefing occurred, which may have adversely affected their ability to cope with an abnormal or unexpected condition. The real altitude confusion took place later in the flight after the crew initiated a climb to 1,500 meters. That confusion is the root cause of the accident.

After takeoff

16:01:35	CVR information indicated that the engines' powers were Increased.	The crew moved the throttles forward.
16:02:18	First officer: "positive climb"	The airplane was in the normal Climb status.
16:02:19	The captain: "gear up"	The first officer retracted the landing gears.
16:02:26	ATC controller: "Korean Air Six three one six contact Shanghai tower one one eight Correction contact Shanghai Departure one one nine-oh [niner] seven five good day"	The tower controller told the KE6316 that he would hand over his control to the Shanghai "departure" controller.
16:02:28	Sounds of auto-pilot trim Tone can be heard in CVR.	The KAL operation procedure allows the crew to engage the A/P while the airplane is at or above 400ft. The crew followed the procedure to engage the A/P and it worked.
16:02:33	The captain: "left turn direct Where"	The captain was not sure to which point they should turn left, he wanted to confirm that with the first officer.
16:02:34	The first office to ATC: "one oh nine three zero ah zero five one one one nineteen zero five Korean Air six six three one six? "	The first officer was busy doing other things while he should be communicating with the ATC. So he wasn't quite clearly sure about the clearance from the ATC. His incoherent reply to the ATC indicated his nervous.

16:02:39	The captain: "Why this do not Turn?"	The crew manipulated the airplane to left, but something unidentified didn't respond as expected, the captain didn't know why.
16:02:40	ATC controller: "negative, one one nine-oh [niner] seven five"	The controller corrected the first officer's previous readback.
16:02:42	four sounds of auto-pilot disconnect warning warbler tones from the CAWS.	The crew disconnected the A/P when they didn't know reason why the airplane didn't respond as expected (see reference at 16:03:05). Meanwhile the first officer pressed the transmit button, the A/P disconnect warning warbler tones was also recorded in the ATC tape.
16:02:46	The captain: "did you engage Direct?" The first officer: "yes"	The captain wondered if the first officer executed the Direct key at the waypoint of their company route. It means that the first officer might have entered an improper waypoint into the FMS previously, Which caused airplane right turn rather than any other failures.
16:02:51	Departure controller: "Korean Air six three one six now turn left direct to November Hotel Whiskey climb and maintain one thousand five hundred meters".	It was normal ATC procedure that the airplane was to be controlled by the "Shanghai departure" after it was airborne.
16:02:52	The aural altitude alert from the CAWS.	The alert indicated that the airplane just passed 600 meter. The crew preselected the initial altitude at 900 meter(3,000ft) the CAWS would be activated when the airplane was at 1,000 ft prior to the preselected

		altitude according to the principle of CAWS.
16:02:58	The captain: "ah, here heading Little ah ah" The SSR plot Indicated that the accident airplane was on the azimuth of about 200° . The heading and the track was almost the same on that day because the wind prevailed was relevantly small.	The captain didn't understand why the airplane had turned right.
16:02:59	The first officer read back to the controller: "okay direct hotel November, November hotel whiskey and say again altitude"	The first officer had clearly received the instruction to NHW, but wasn't really quite sure about the altitude.
16:03:05	The first officer: "why this not Work?" The captain: "make it turn, it doesn't turn, something's wrong with this airplane today"	The crew had got some troubles with the lateral control, the possible explanations could include: 1.the first officer improperly entered the FMS, which caused the airplane to turn right; or 2. The crew didn't engaged the NOV mode after the FMS entry; or 3.There might be some malfunction of the heading control or; 4. There might be omething wrong with the heading selection knob.
16:03:06	The first officer: "okay let's Turn." The flight track was straight During the phrase according to the SSR plot.	Though the crew seemed to have some difficulty in getting the airplane to turn left, it does not appear to be a problem with the lateral control or other systems, because the crew could keep the airplane in level

		flight and in a steady climb. The crew didn't mentioned any specific airplane or airplane system anomaly in its discussion, furthermore, they didn't request a return to the airport. All of which indicate that the airplane flight control and operating systems were functioning normally, as well as the pitch control.
16:03:08	The ATC clearance: "Korean Air six three one six climb Maintain one thousand five hundred meters."	ATC saw that the airplane didn't turn to NHW and gave KE 6316 another instruction direct to NHW and repeated the altitude.
16:03:10	The captain: "I don't see, Where"	The ND range on the captain side could be 10 mile in the normal operation at this moment, therefor he couldn't see the NHW on his side. So he asked the first officer where the NHW was.
16:03:13	The first officer: " yes, here Keep turning left, keep turning left	The ND range on the first officer's side might be greater than 10 miles, so the first officer saw NHW on his ND, knew where it was, and instructed the captain to keep turning left, but he didn't readback the altitude clearance to ATC.
16:03:17	The captain: "three thousand Feet hold." The SSR plot indicated that The airplane climbed to 3,000 Ft, and steadily kept on that Altitude.	The airplane climbed to and maintained 3,000 feet. The captain mentioned the altitude in feet rather than meters. This suggests that the captain still believed that the altitude clearance was in feet not meters.

16:03:29	The captain: "flaps up." The first officer: "yes"	The crew retracted the flaps.
16:03:31	ATC controller repeated the Instruction: "Korean Air six three one six, climb and maintain one thousand five hundred meters"	ATC found that the airplane stayed at 900 meters, and hadn't acknowledged their new clearance to 1500 meters, so ATC reissued the climb instruction.
16:03:35	The first officer answered the ATC: "one thousand five Hundred meters Korean Air six three one six."	The first officer heard that the climb instruction was 1,500 meters from ATC.
16:03:37	The captain: "It might turn Upside down. What's wrong with this?" The SSR plot indicated that the airplane didn't turn much to the left.	The crew continually controlled the airplane to the left, but the bank angle was too small. A possible reason for this could be that the lateral command bar of the flight director (FD) was still indicating a right turn, if the crew hadn't changed a previous right turn selection. The captain still may not have understood that.
16:03:40	ATC repeated the instruction: "Korean Air six three one six left turn direct to November Hotel Whisky."	The reason why ATC repeated its left turn instruction was because the airplane still drifted to the right.
16:03:43	The first officer readback: "November ah November Hotel Whiskey Korean Air Three six one six."	Now the first officer heard clearly the instruction to NHW From ATC.
16:03:45	The first officer: "Thank you Sir"	The first officer expressed his thanks to the captain for his help.
16:03:47	The captain: "Are they asking Us?	The captain wanted to confirm the ATC climb clearance with the first officer.
16:03:49	The first officer: "yes, they are Telling us to climb up"	The captain's words reminded the first officer of the ATC new

		altitude clearance. He then armed the altitude at 4,900ft(1,500m), meanwhile he was ready to engage the NAV mode.
16:03:52	The captain agreed with the First officer's suggestion: "okay engage NAV" The first officer: "yes"	The captain allowed the first officer to engage the NAV on flight control panel (FCP).
16:03:53	The captain: "ah why."	The captain might find something.
16:03:54	The first officer: "slat why it Doesn't work? Slat, slat up"	The first officer at that moment found that the slats were not retracted, so he reminded the captain about that.
16:03:58	Sound similar to flap handle Being moved.	The slats were retracted at last by the crew.
16:03:59	The altitude on the SSR plot Was 970 meters (3200ft).	This indicated that the pitch control was normal, the airplane changed from level flight at 900 meters (3,000 feet) to a climb status.
16:04:03	The captain: "ah sh" The first officer: " yeah now it Works oh phew"	The slats were retracted and the airplane was in a clean and normal configuration.
16:04:05	The captain: "well what's Wrong with this airplane today?"	The captain felt the flight was not beginning well.
16:04:06	The captain: "uh oh look at this" The first officer: "oh"	Something might catch the captain's attention.
16:04:07	Two sounds of "altitude" alert Tone.	The crew might arm the altitude at 1,500 meters (4,900ft). The altitude alert system was active while the airplane reached the altitude 3,900 ft according to the altitude alert system design principle (see section2.6.1). The two consecutive altitude

		warnings were active due to excessive climb rate
16:04:10	The first officer: "pitch sir"	The captain didn't follow the pitch director bar, and there was a big difference between the aircraft's actual pitch attitude and the flight director-commanded pitch attitude bar. The first officer reminded the captain when he saw the big difference. The investigative team notes that the captain did not appear to concentrate on keeping the proper airplane attitude, and appeared to be distracted by other things.

Although the crew had discussed some problems like heading and others between the time of takeoff at 16:01:35 and 16:04:10, and they reengaed the NAV mode at 16:04:03. After the slats retracted at 16:04:30, the airplane was in a normal condition of flight, and the crew didn't report any emergency condition or asked a return to the departure airport, on the contrary they continued to climb for departure. The radar data and the crew conversation indicate that the airplane didn't have any significant malfunctions, otherwise the crew should have reported and requested to return immediately.

16:04:12	The captain asked the first Officer: "how far did they tell us to climb?"	The captain was not familiar with the departure procedure for Shanghai and he was doubt about the altitude clearance (as Reported by the first officer).
16:04:13	The first officer: "fifteen Hundred feet"	The first officer mistakenly reported their altitude clearance to the captain as 1500 feet.
16:04:14	The captain: "ah ah woo"	The first officer's answer verified the captain's previous doubt about the altitude clearance. But he wanted to

		make sure, so he asked the first officer again.
16:04:15	The first officer was surely Answered altitude clearance: "fifteen hundred feet"	The first officer was totally wrong about the altitude.
16:04:17	The first officer : "Why isn't it working? Wait wait wait ah ah oh."	His remark might refer to the throttles.
16:04:19	The captain: "throttle throttle Throttle" in a hurry.	Now the captain believed that his airplane was 3,000 feet higher than their ATC clearance. As a pilot he understood that it was dangerous to be so far off his assigned altitude in a vicinity of a busy airport. Under these circumstances, he may have pushed the control column forward or applied other control inputs to initiate a rapid descent back to his assigned altitude. The airplane consequently made an abrupt transition from a climb to an extreme descent. The first officer armed the altitude window at 1500 feet, while the airplane was climbing at climb power, however, the throttles did not retard or were not retarded immediately, so the captain asked the first officer to help him with reducing the throttles.
16:04:19	The captain: "just a moment just a moment uh"	The first officer might help pushing the control column, his action might aggravate the pitch attitude change. The captain noticed that the control column input was too harsh and

		excessive.
16:04:19	The SSR plot indicated that the airplane was at its highest point,1370 meters(4,500 ft) of the accident flight, and then disappeared from the screen.	The initial force of the airplane made the airplane climb to its highest point, 1,370 meters (4,500 ft), though the crew pushed hard at the beginning. The radar display didn't suggest that there was any aircraft around, and no report from the other aircraft. There was not such a possibility that the crew wanted to avoid the conflict on the basis of analyzing crew's talk and their long time overtrim the stabilizer.
16:04:20	Sound of whistle followed by an altitude alert tone.	The first officer might be changing the original altitude setting, and the target altitude was not armed yet during his selection, but he might pull out the altitude setting knob due to the sudden attitude change of the airplane. Therefor we can't determined at what altitude the alert was issued, but this may further explain that the crew had changed the altitude setting of 4,900ft during this period of time.
16:04:20	Sounds of trim in motion tone from CAWS	The crew used nose down stabilizer trim while they pushed the column forward.
16:04:21	The rattling sounds similar to a rattling dash or glare shield panel in the cockpit.	Objects in the cockpit, which were not well tightened, rattled, due to the violent attitude change.
16:04:22	The first officer: "wait, wait Pitch ..."	The first officer called the captain attention to the pitch attitude due to the violent attitude change.

16:04:22	The captain: "yah yah yah yah yah yah yah yah"	The violent attitude change caused the cockpit in chaos.
16:04:24 --- 16:04:30	Three consecutive "Stabilizer Motion" aural tones from CAWS.	The crew continuously used stabilizer trim to balance the force on the column during the descent, The sound of "Stabilizer Motion" can only be heard after continuous movement of more than 0.2 degree of stabilizer travel (the warning principle see section 2.6.5), which can be concluded that the crew deliberated to dive to a low altitude.
16:04:26	Rattling sounds stopped.	
16:04:27	The captain: "Unusual"	It might refer to the rattling sounds.
16:04:27	"Altitude" from CAWS.	The first officer armed the altitude at 1,500ft, the altitude voice alert can be heard when the airplane passed 2,500 feet, according the principle. If the altitude was armed at 4,900 feet, the voice alert would have been heard as the airplane descended through 3,900 feet. If this were the case, the descent height of the first 8 second would be 600 ft, and average descent rate would be 4,500 feet per minute, and the airplane would never disappear from the radar. We confirm that the crew had changed their original altitude setting(4,900ft) with the reference to the altitude alter at 16:04:20
16:04:28	The same rattling sound Appeared again.	The airplane attitude might change violently again, which caused rattling again during the

		rapid descent.
16:04:29	The first officer: "nose up, Nose up nose up"	The first officer might have heard the altitude alert, or seen the ground through the opening in the clouds, he realized their proximity to the ground, so he called for the captain to pull up. The first officer only reminded the captain to pull up at this moment rather than at the initial Descent, which further indicates that they were anxious to descend to 1,500ft. If the crew had known the elevator malfunction, they should talked about that rather than calling like this.
16:04:31	The captain: "ah?"	The captain didn't realize that the airplane descended so quickly within the previous 12 seconds from 4,500ft, and when he heard the first officer calling his attention to pull up, but he didn't know why.
16:04:31	The warning "terrain terrain" From GPWS.	The rapid descent and a low altitude activated the ground proximity warning system (GPWS) to issue the "terrain terrain" warning.
16:04:32	The first officer : "nose up Nose up nose up"	The first officer might see the ground clearly, and know the descent rate was too high, and know the peril ahead, so he pulled back the column hard together with the captain out of his instinct and yelled loudly.
16:04:33.6	"woop woop pull up" from the GPWS. CAWS: "1,000"	According to the altitude alert principle, the CAWS would issue an altitude deviation alert when the airplane was 150 ft

		deviated away from the armed altitude. The CVR should have recorded the deviation alert at 1,350ft, but at this moment the GPWS might have detected the possibility of crash and issued the aural warning "pull up", which was louder than the deviation alert. Meanwhile the airplane was just passing the 1,000ft that would activate the CAWS to issue altitude alert "1,000".
16:04:33	The first officer: "unable Control lift up"	The first officer realizes that there was not enough altitude remaining for recovery prior to impact.
16:04:34	"woop woop pull up" from GPWS	The crew might try to recovery from the pulling back.
16:04:35	The end of CVR recording.	The airplane crashed during its recovery from dive at a descent rate of about 30,000 ft/m according to the GPWS manufacturer measurement.

Brief summary:

The investigative team notes that the crew mistook the 1,500m altitude clearance (from the ATC) for 1,500ft,during the time between 16:04:12 and 16: 04:35, which caused the crew to think that their altitude was much higher than the cleared altitude and then harshly pushed the control column forward with the overtrim of the horizontal stabilizer. The low cloud layers hampered the crew's situational awareness of the altitude,. The airplane crashed due to the low altitude and late action of pulling back the control column.

2.9 The probable causes of the airplane sudden dive

2.9.1 The Weather factors

The prevailing weather on April 15, 1999 was indicated that there was no adverse weather along the flight path of the accident airplane. The investigative team excludes the possibility that the accident airplane sudden dive was caused by the weather.

2.9.2 The mechanical problems

2.9.2.1 The horizontal stabilizer

The horizontal stabilizer position will not change suddenly in terms of movement of the jackscrew within a short period of time due to its jackscrew structure. Therefor the airplane will not suddenly dive because of the horizontal stabilizer failure.

If the electrical trim fails, the manual trim can override it.
If the trim is completely out of control, manually pulling the control column to its end position will make the airplane nose up.

2.9.2.2. Elevator

2.9.2.2.1 Jammed Elevators

If the elevators were jammed while the accident airplane was climbing, they should have most likely jammed in a nose up position or a faired position rather than a nose down position. The airplane would continue its climbing rather than descending. Further more if they jammed in a nose down position and the crew tried to pull up, the crew could have trimmed the stabilizer in the nose up direction to help maintain control of the airplane rather than forwards.

2.9.2.2 Elevators Jammed Full Trailing Edge Down

If the elevators were all jammed at the extreme position of pitch down, the impact angle of the airplane would be between 70-90 degrees nose dowm. In this case, there would not have been any GPWS or CAWS "1000" feet warnings due to the limitations of the radar altimeter system. Therefore we can preclude the possibility of jamming of the elevators.

The investigative team excludes the possibility that the accident airplane sudden dive was caused either by the horizontal stabilizer out of control or by elevator failure.

2.9.3 Human factor

2.9.3.1 The crew health status

The investigative team excludes the crew health that might cause the airplane sudden dive according to the analysis on subsection of 1.5.1.

2.9.3.2 Violent act (inter-crew or third person)

The investigative team excludes the possibility of inter-crew's or third person's violent act that might cause the airplane sudden dive on the basis of CVR information and DNA examination result.

2.9.3.3 The crew human factor error

The crew reconfirmed the wrong altitude and abruptly pushed the control column forward and overtrimmed the horizontal stabilizer forward.

2.9.3.4 The basis of the crew human factor error

The crew mistook the cleared altitude twice as 1,500m for 1,500ft in their cockpit conversations.

There was no such a possibility that the crew armed the altitude at 4,900ft. The crew most probably armed the altitude at 1,500ft, which coincided with their reconfirmation of the wrong altitude.

The crew continuously trimmed the horizontal stabilizer forward in order to descend quickly and counteract the force on the control column, which caused the horizontal stabilizer position to decrease from approximately 2.4 degrees in a status of climb to 0.65 degree.

The first officer didn't call out to pull up at the initial of descent, but only before crash.

The above mentioned evidences indicate that the accident airplane sudden dive was at the wish of the crew rather than other causes.

3.Conclusion:

3.1 Findings

1. There was no evidence of pre-impact explosion or sabotage.

2. The ATC controllers handling the accident flight were not causal to this accident.

3. The cargo loading and weight and balance were within the airplane's Limitations, and KAL's operating practices. There is not enough room for the cargo to shift.

4. All the engines worked properly during the accident flight.

5. Based on all the available evidence, it appears that the hydraulic systems functioned normally during the accident flight.

6. Since the flight crew performed a control check after starting engines, with no comments, the flight control system was functioning normally at that time.

7. The captain didn't provide a takeoff briefing before departure, so the crew was not well prepared for confusing or unexpected situations. Therefore, the crew couldn't react in a timely manner when they felt confusion or experienced unexpected situations.

8. The flight crew's comments during the initial portion of the flight, regarding heading and the need to turn towards the first navigational fix, did not specify what sort of difficulties or confusion the flight crew was actually experiencing.

9.The flight crew comments during the initial portion of the flight regarding their heading and the need to turn left were consistent with the crew that thought that they had programmed the aircraft's autoflight system to do something, and the aircraft subsequently did not respond as expected. These unexpected responses typically result from inadvertent or erroneous flight crew inputs. Later in the flight, prior to the transition from rapid climb to rapid descent, both pilots appear to acknowledge that the source of their heading confusion had been resolved.

10. The autopilot was disengaged shortly after takeoff and the airplane's radar-recorded flight path indicated that the airplane maintained a heading (roughly 200 degrees magnetic heading) and altitude (approximately 3,000 feet or 900 meters) prior to turning left toward the NHW VOR and initiating a climb to 4,900 feet (1,500 meters). The flight crew did not mention or discuss any annunciated alerts, warnings, or cautions during this time period; nor did they refer to any specific flight control or other aircraft systems concerns.

11. The flight crew did not discuss nor did they request a return to the departure airport, nor did they declare an emergency, indicating that their confusion and/or concerns were minor in nature.

12. The crew was confused before and during the flight by the altitude clearances, and they continuously expressed difficulty in understanding if the altitude assignments were in feet or in meters.

13. The radar-recorded flight path and altitude profile indicated that the airplane transitioned from a rapid climb to a very rapid descent.

14. The captain abruptly pushed the control column forward after he received further (but mistaken) confirmation from the first officer that their clearance altitude was 1,500 feet instead of 1500 meters. This confirmation came while the airplane was in a rapid climb and nearing 1,500 meters (4,900 feet). The abrupt control inputs resulted from the captain's mistaken belief that he was 3,000 feet higher than their ATC clearance.

15.The crew attempted to recover from the dive when they realized that they were descending too rapidly.

16.The airplane impacted the ground at a speed of approximately 398 knots, in a wings level attitude, and at between 20-40 degree nose down pitch attitude, due to the high descent rate and late recovery attempt.

17. There was no evidence that indicates that there were apparent major malfunctions among the accident airplane's operation and flight control systems .

18. Simulator flight test attempts to duplicate the radar-recorded altitude and flight path profile (including the transition from rapid climb to very

rapid descent), the CAWS and GPWS alerts recorded on the CVR, and information derived from witness reports, indicated that the airplane could not duplicate the accident profile with runaway nose-down stabilizer trim or with the elevator out of control. Therefore, the accident flight path profile appears to have been the result of deliberate flight control inputs.

19. The investigative team doesn't exclude the possibility of negative G stall, resulting from sudden attitude change, which aggravated the pitch-over.

20.The investigative team doesn't exclude the possibility of some partial malfunction on the airplane. If there was some, but that was not the cause of the accident.

3.2 Probable Cause

The joint investigative team determines that the probable cause of the Korean Air flight KE 6316 accident was the flight crew's loss of altitude situational awareness resulting from altitude clearance wrongly relayed by the first officer and the crew's overreaction with abrupt flight control inputs.

Note: this conclusion is only the most probable cause, which can't be used as lawsuit.

4. Safety Recommendations

4.1 Korean Air shall train its pilots to be familiar with converting meters to feet, and provide training for proper cockpit discipline in ATC environments using meters for altitude clearances.

4.2 Korean Air shall reinforce its pilot crew resource management training, require its pilots to adhere strictly to established procedures including the conduct of briefings, cockpit crew preparation and organization prior to flight, and prohibit its pilot crews from beginning a flight until all necessary preparations are complete and the flight crew is in agreement on how the flight will be conducted.

4.3 Korean Air shall reinforce the pilot flight techniques and psychological training to improve the pilots' competence in dealing with abnormal conditions during flight.

4.4 Korean Air shall pay close attention to crew qualification and scheduling according to the differences and peculiarities of the routes, destination airports and nations.

4.5 The flight data recorder manufacturers should enhance the crashworthiness of the flight data recorder so that they can survive in the accident.

4.6 Since the air traffic control altitude assignment is issued in different measuring units in different nations, it is suggested that the international aviation community strengthen the cooperation and take effective measures to avoid the crew's confusion of the different measuring units of the ATC clearance and step up to use the same altitude measuring unit in the ATC assignment.

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Appendix1: Name list of the investigators

Position in the investigative team	Name	Title
Investigator in Charge:	Ye YiGan	The Director General of ECA of CAAC
Deputy IIC:	Wang XuanWen	The deputy Director General of ECA, CAAC
	Li JunMing	The deputy Director General of ECA, CAAC
	Wu ShunSheng	Senior investigator of Flight Standard Dept., CAAC
Comprehensive group		
Group lead:	Zhang XiaoDong	The director of Aviation safety office ECA, CAAC
Group member:	Zhang Fa	The deputy director of Aviation safety office ECA, CAAC
	Tang weibin	The Aviation safety investigator of Aviation safety office ECA, CAAC
	Guo Fu	The Aviation safety investigator of Aviation safety office ECA, CAAC
	Wu Yibing	The deputy Director of Aviation safety office ECA, CAAC
Flight operation group		
Group lead:	Guo YouHu	The Director of flight standard dep. of ECA, CAAC
Group member:	Yang ChunLei	The inspector of flight standard dep. of ECA, CAAC
Airworthiness group		
Group lead:	Shen Xiaoming	The deputy director of Airworthiness dep. ECA, CAAC
Group member:	Meng Huiming	The director of Airworthiness Division of CAAC
The ATC group		
Group lead:	Guo zhongyue	The director of Accident investigative Division of CAAC
Group member:	Chao Gong	The inspector of flight standard dep. of ECA, CAAC
	Xia Qing	The Aviation safety investigator of Aviation safety office ECA, CAAC
Transportation group		
Group lead :	Li JinGao	The deputy Director transportation dep. of ECA, CAAC
Group member:	Song QinHua	The director of transportation Division of CAAC

Security group		
Group lead :	Gu QiMing	The deputy director of the public Security Dept. of EAC, CAAC
Group member:	Yang Dong	The security inspector of the Natonal Security Dept. of China
	Zhang ZhongKui	The deputy director of the public Security Dept. of CAAC
	Tang HaiXing	The deputy director of the public Security Dept. HongQiao Airport.
The liaison	Zhang GuoHua	The deputy director of adminstrativie office of EAC, CAAC

Other members of the joint team

The accredited representative of Korea Republic.

Lee, Woo-Jong	Director of Aviation Safety Division, Civil Aviation Bureau of KCAB.

The advisors to the accredited representative of Korea Republic.

Park, Hyang-Gyu	Director, Air traffic Control Division Flight Standards and ATS Bureau, Seoul regional Aviation Office of KCAB
Yoo, Byung-Sul	Deputy Director, Aircraft certification Division, Civil Aviation Bureau of KCAB
Yoo, Byung-Yul	Accident Chief Investigator, Aviation Safety Division, Civil Aviation Bureau of KCAB.
Man Heui, Chang	Chief Inspector, Airworthiness Division, Aircraft Safety Bureau Seoul Regional Abiation Administration of KCAB.

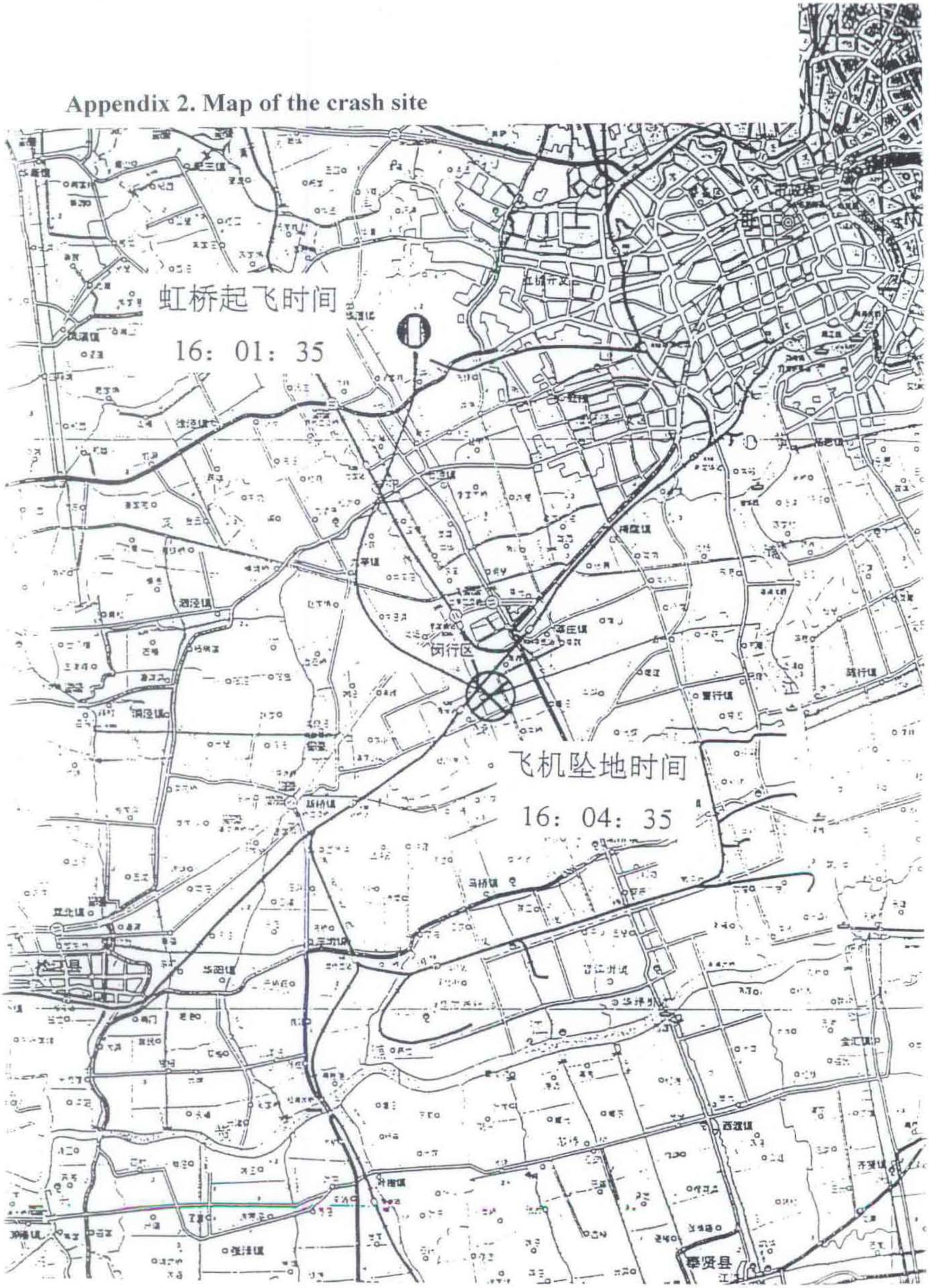
The accredited representative of United States of America.

Alfred W. Dickinson	Investigator-in-Charge, Office of Aviation Safety, Major investigations Division, NTSB.

The advisors to the accredited representative of the United States of America.

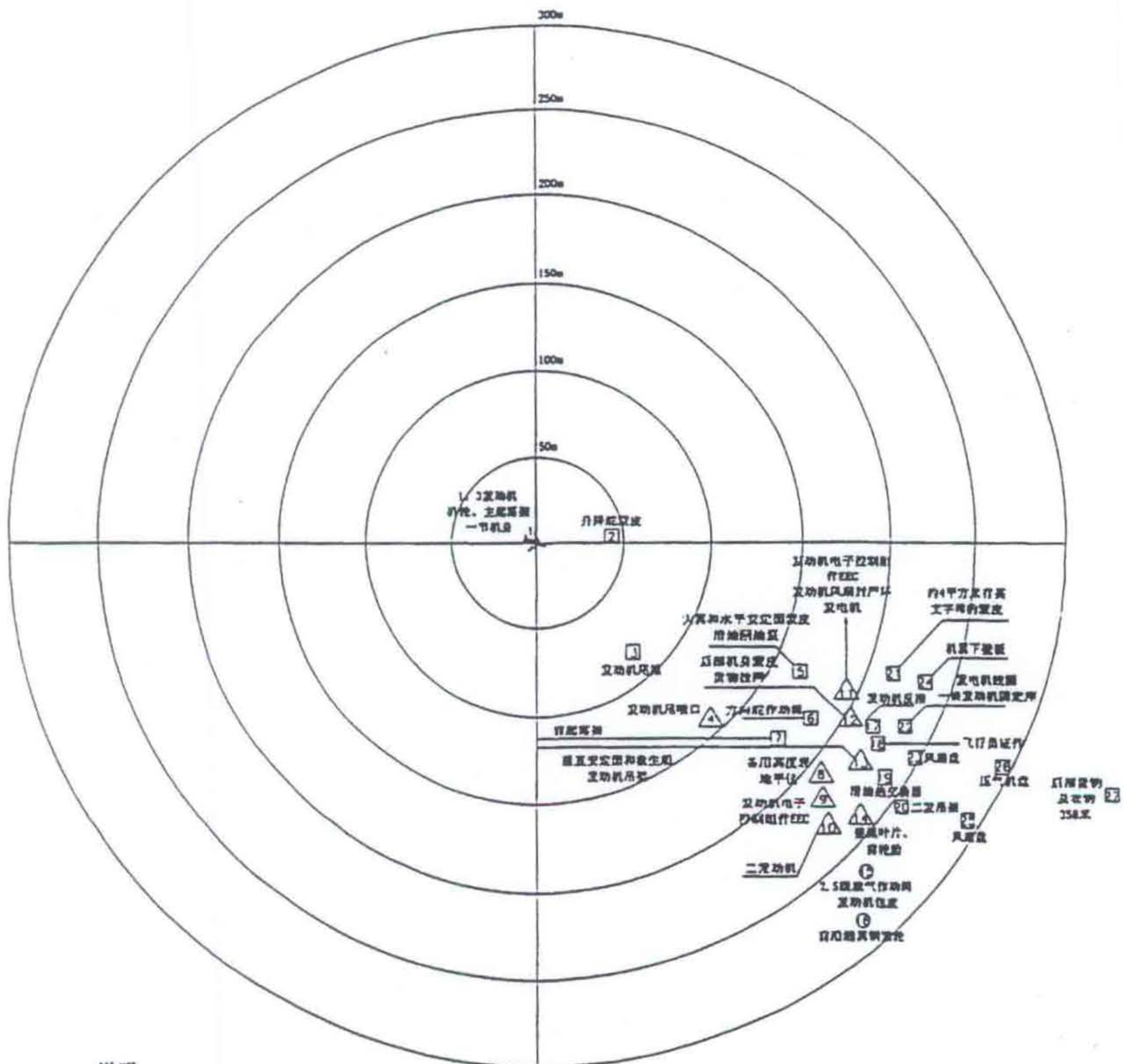
Dave Tew	Captain, Aviation Safety Investigator, Operation, Office of Aviation Safety, NTSB.
Gordon J. Hookey	Aerospace Engineer, Powerplants, Aerospace Engineer, Powerplants, Office of Aviation Safety, NTSB
Kevin M. Pudwill	Aerospace Engineer, Structures, Aviation Engineering Division, NTSB.
Victoria Anderson	Air Safety Investigator, Office of Accident Investigation, FAA.

Appendix 2. Map of the crash site



Appendix 3. Wreckage distribution chart

″4.15″空难飞机残骸分布示意图



说明：

一、失事地点：N31° 06′ 00″ E121° 22′ 16″

二、位于虹桥机场跑道中心：165° 11.6公里

三、在跑道延长线东侧2.3公里

四、机头方向约110°

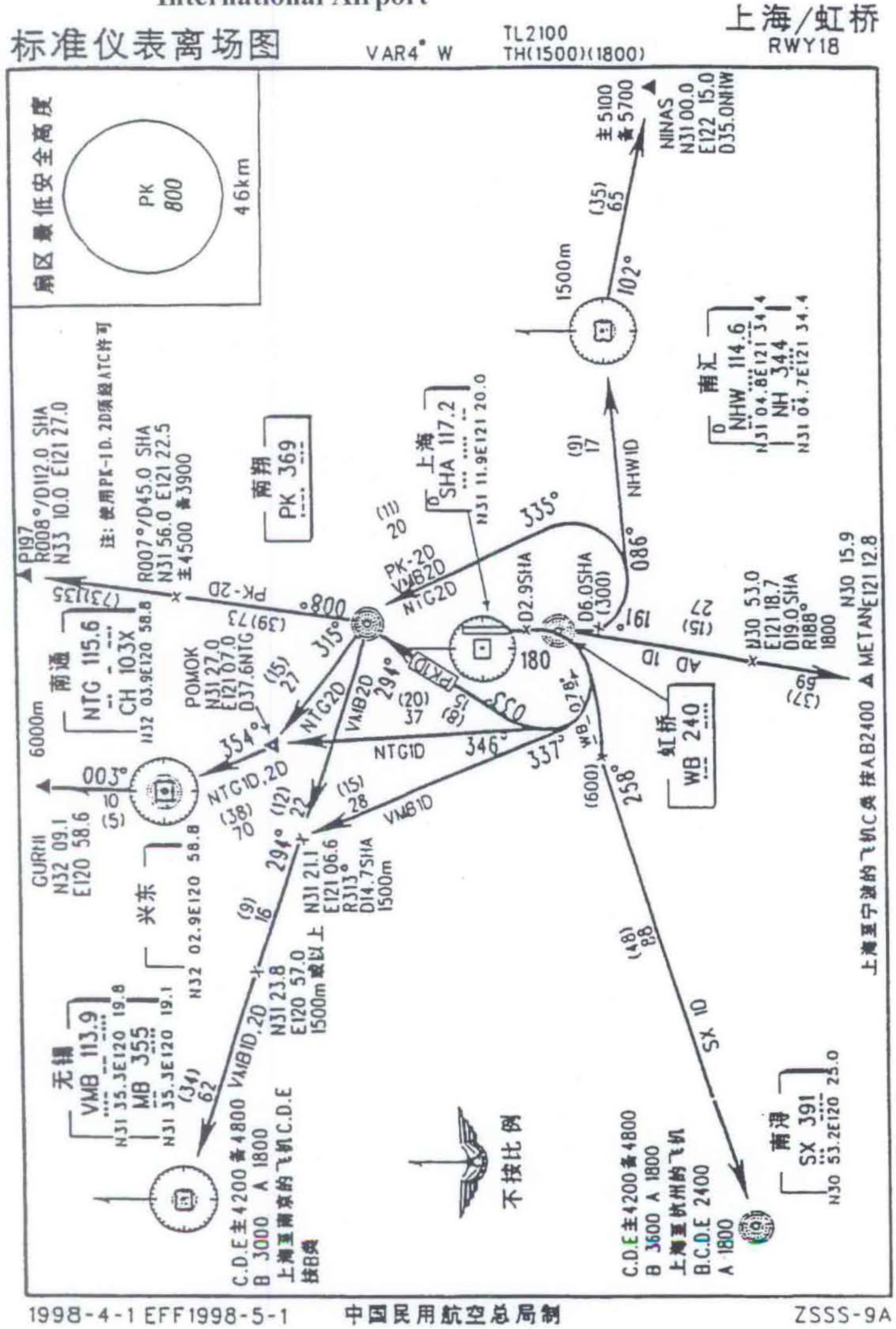
五、 [?] 救生船挂在二楼

[?] [?] 在二楼内

[?] 在四楼房顶

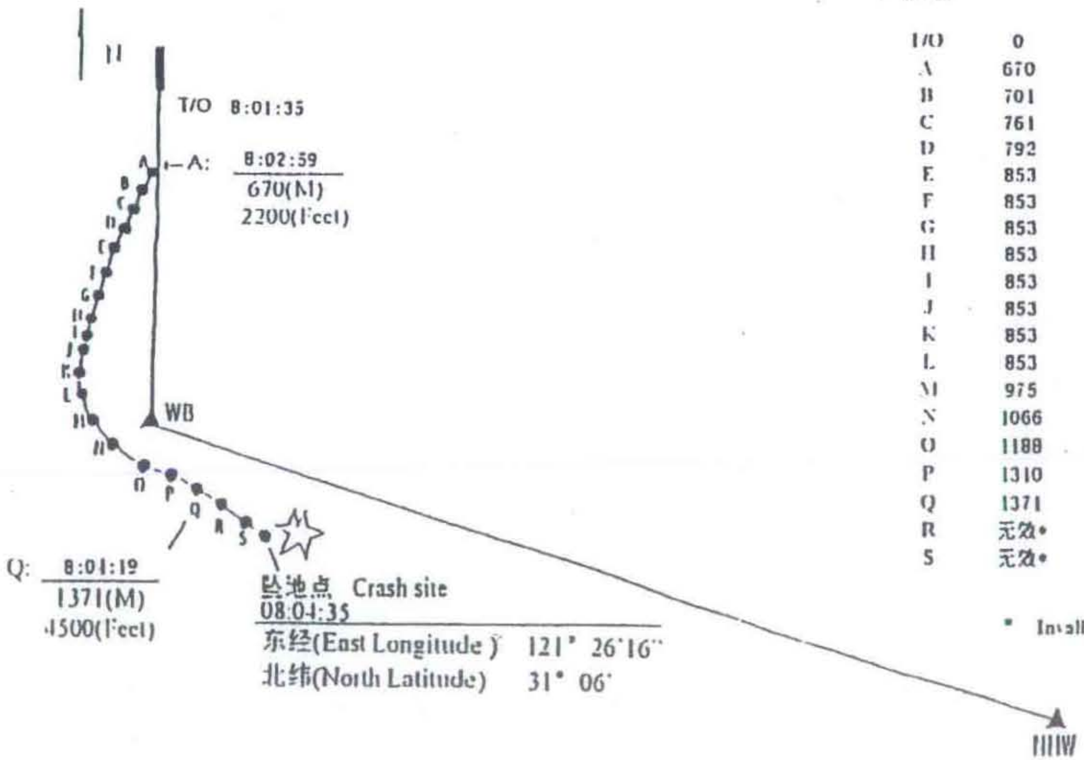
六、三名机组人员遗骸距中心60—70米

Appendix 4. The SID chart of runway 18 of Shanghai HongQiao International Airport



Appendix 5. The SSR plot of Korean Air MD-11, KE 6316 flight, Korea registration HL7373, Shanghai accident on April 15,1999

"4.15"事故雷达录象示意图
"4.15"Accident SSR Vedio Record Schematic diagram



位置点 Points of the track	高度 (M) Altitude	高度 (Feet) Altitude	相对两次雷达距离 (KM) Distance to SSR	方位 Azimuth	时间UTC UTC Time
T/O	0	0	0		8:01:35
A	670	2200	3.13	196.78	8:02:59
B	701	2300	3.48	199.78	8:03:04
C	761	2500	3.81	200.39	8:03:09
D	792	2600	4.19	201.09	8:03:14
E	853	2800	4.75	203.12	8:03:19
F	853	2800	5.06	204.35	8:03:24
G	853	2800	5.44	204.87	8:03:29
H	853	2800	6.25	204.87	8:03:34
I	853	2800	6.63	203.82	8:03:39
J	853	2800	6.94	202.24	8:03:44
K	853	2800	7.63	197.84	8:03:49
L	853	2800	7.98	194.94	8:03:54
M	975	3200	8.44	189.4	8:03:59
N	1066	3500	8.69	186.59	8:04:04
O	1188	3900	8.94	184.22	8:04:09
P	1310	4300	9.13	181.76	8:04:14
Q	1371	4500	9.63	177.54	8:04:19
R	无效*		9.81	175.61	8:04:24
S	无效*		10.06	173.76	8:04:29

* Invalid

Appendix 6: CVR transcripts:

START of transcript

1542:12
RDO-2 good afternoon Hongqiao tower Korean air six three one six

1542:52
TWR six three one six stand by.

1543:01
TWRKorean air six three one six go ahead

1543:04
RDO-2 request clearance to Kimpo airport ah flight level two nine five spot nine one one have Kilo

1543:12
TWR roger stand by for ATC clearance

1543:16
RDO-2 okay standing by we are ready for pushback

1543:20
TWR Korean air six three one six pushback and startup approved

1543:23
CAM-1 roger

1543:24
RDO-2 okay pushback and startup approved Korean air six three one six

1543:30
INT-1 ground cockpit

CAM-1: Captain, CAM-2: First officer, CAM-3: Flight technician, CAM: Cockpit background noises, INT-1: Captain intercommunication, INT-4: Ground intercommunication, RDO-2: the first officer radio communication, TWR: Tower clearance.

1543:31
INT-4 ah go ahead

1543:34
INT-1 okay pushback runway one eight
1543:39
INT-4 ah roger

1543:43
CAM-1 checklist beacon light

1543:45
CAM-2 before start checklist sir

1543:46
CAM-2 doors windows?

1543:47
CAM-1 closed and locked

1543:48
CAM-2 closed, parking brake?

1543:49
CAM-1 released

1543:50
CAM-2 released, beacon?

1543:52
CAM-1 on

1543:54
CAM-2 on, engine ignition?

1543:55
CAM-1 standby

1543:56
CAM-2 standby, fuel panel auto, air panel auto, before start

checklist complete

1544:07
CAM-1 driver hasn't arrived yet
1544:21
INT-4 ah captain ah release the parking brake

1544:26
INT-1 okay brake released

1544:30
CAM-1 brake released

1544:24
CAM-1 why this brake *

1544:46
CAM-2 before start checks complete

1544:47
CAM-1 roger

1545:51
CAM-2 pressure okay

1544:54
INT-1 start engine three one two

1544:57
INT-4 ah stand by after pushback complete

1545:01
INT-1 roger

1545:12
CAM-1 it's a sonata sonata

1545:17
CAM-2 yeah

1545:24
CAM-1 why brake differential comes on, why brake diff-temp comes on

1545:29
CAM-1 well something's not right, this brake temp not raised at all

1545:33
CAM-2 it looks okay, uh what's wrong with this, it seems this brake not released

1545:35
CAM-3 no, this is brake temperature

1545:38
CAM-1 huh

1545:39
CAM-3 it's number eight

1545:41
CAM-3 number eight shows abnormal

1545:43
CAM-1 it is three hundred eighty

1545:46
CAM-3 no that's not actual indication that indicates abnormal

1545:51
CAM-1 that was not that hot, I wonder what's going to happen when we takeoff, anyway it's dropping down

1545:57
CAM-2 yes it dropping down

1546:04
CAM-3 when we made landing, number eight brake temp showed up

1546:10
CAM-3 it shouldn't rise up alone on that area

1546:22 INT-4 ah captain cleared to start three one two

1546:27
INT-1 roger starting number three

1546:32
CAM-2 starting number three valve open

1546:34
CAM-1 valve open

1546:37
CAM-1 N-2 it keep giving me trouble

1546:37
CAM-2 N-2

1546:46
CAM-1 ((sound of laugh))

1546:57
CAM-1 max motoring, fuel on, time check

1546:59
CAM-2 time check

0747:00
CAM-1 lightning bolt EGT

1547:03
INT-4 ah Captain set parking brake

1547:05
CAM-2 three seconds

1547:04

INT-1 roger brake is set

1547:14
CAM-2 N-1

1547:16 CAM-1 *

1547:33
CAM ((sound of snap))

1547:33
TWR one six copy ATC clearance

1547:34
CAM-2 forty five valve closed

1547:36
CAM-1 peak EGT

1547:37
1548:00
CAM-2 sir

1547:42
RDO-2 go ahead Korean Air six three one six

1547:44
TWR Korean Air six three one six clear to destination flight planned route flight level two niner zero. after departure turn left direct to November Hotel Whiskey. initially climb and maintain niner hundred meters. departure frequency one one niner zero five. squawk six three one six.

1547:49
CAM-3 it's working well now

1547:50
CAM-1 what

1548:51

CAM-3 *

1547:54
CAM-2 three two five, stabilize

1547:56 INT-1 start engine number one
1547:58
INT-4 okay

1548:01
CAM-1 valve open

1548:04
CAM-2 open

1548:05
RDO-2 Korean Air six three one six clear to destination ah flight planned route maintain flight level two nine zero. departure frequency one nineteen seven five. squawk six three one six. after takeoff turn left to November Hotel Whiskey initially nine thous - nine hundred meters

1548:06
CAM-1 N-2

1548:09
CAM-1 *

1549:03
CAM-1 nine hundred meter?

1549:07
CAM-1 isn't that one thousand feet?

1549:22
INT-1 okay start engine number two

1549:24
INT-4 okay

1549:45
TWR Korean Air six three one six read back correct.
1549:49
RDO-2 okay just sir ah I will make sure about initially maintain nine hundred meters then after takeoff left turn direct to November Hotel Whiskey. is that correct?

1550:01
TWR that's that's affirmative.

1550:05
CAM-1 is it nine hundred meters?

1550:07
RDO-2 Korean air six three one six

1550:10
CAM-2 yeah nine hundred feet, we don't need this and it is radar vector, you may go to November Hotel Whiskey just right after takeoff, they didn't give me a SID

1550:23
CAM-2 let's change it to meter, nine hundred meter nine hundred meter, we need to head to November Hotel Whiskey right after climb to four hundred feet. squawk six three one six

1550:38
CAM-1 okay, it still keep giving me a trouble

1550:41
CAM-2 three one six

1550:43
CAM-1 after start checklist

1550:45
CAM-2 sir, after start checklist

1550:48
CAM ((sound similar to flap handle being moved))

1550:51
INT-1 okay disconnect all equipment please

1550:54 CAM-2 after start checklist sir
1550:55 INT-4 *

1550:57
CAM-2 anti-ice not required, air panel auto, APU off

1550:59
CAM-1 off

1551:00
CAM-2 hydraulic panel auto, ground equipment gear pin

1551:03
CAM-1 removed

1551:04
CAM-2 removed, cabin report not necessary

1551:06
CAM-1 received

1551:07
CAM-2 after start check's complete sir, control check left

1551:17
CAM-2 right, up, down

1551:21 CAM-1 okay

1551:41
CAM-1 it keeps coming on, it keep giving me a trouble

1551:32
CAM-2 yes

1551:41

RDO-2 Hongqiao tower Korean Air six three one six request taxi.

1551:46
TWR Korean Air six three one six taxi via kilo seven tango zero for runway one eight.
1551:53
RDO-2 kilo seven tango... tango zero runway one eight Korean Air three six one eight ah six three one eight.

1551:55
CAM-1 kilo seven tango zero runway one eight

1552:02
CAM-1 right side clear?

1552:03
CAM-2 right side clear sir

1552:04
CAM-1 left side clear

1552:09
CAM-1 kilo seven parallel, is tango ten at the end over there?

1552:15
CAM-1 uh where is tango ten?

1552:16
CAM-2 tango, tango zero all the way end

1552:18
CAM-1 all the way end?

1552:19
CAM-2 yeah

1552:23
CAM-1 ah brake temp rise up four hundred

1552:32

CAM-2 here is kilo seven

1552:33
CAM-1 roger

1552:34
CAM-2 right side clear

1552:39 {
CAM-2 it keeps coming on

1552:42
CAM-2 definitely something's wrong

1552:44
CAM-1 umm

1552:45
CAM-2 rather... definitely there's some problem..

1552:49
CAM-3 it rise up to four hundred *

1553:02
CAM-2 right side clear, right turn

1553:04
CAM-1 roger

1553:31
CAM-1 okay taxing checklist

1553:33
CAM-2 taxi checklist sir, flaps?

1553:35
CAM-1 twenty eight

1553:36
CAM-2 twenty eight, spoilers?

1553:38
CAM-1 armed
1553:38 CAM-2 armed, flight controls?

1553:40
CAM-1 checked

1553:41
CAM-2 checked, stabilizer trim?

1553:43
CAM-1 set, six point niner

1553:44
CAM-2 set, takeoff data

1553:46
CAM-1 confirm and set one three five, one four seven, one five six

1553:59
CAM-1 turn on the direct after airborne

1554:05
CAM-1 let's make it turn at four hundred ten

1554:11
CAM-1 why they provide clearance while we making start

1554:20
CAM-1 now it's seventy seven

1554:24
CAM-1 it's normal now, before it rise up rapidly

1555:00
CAM-1 the runway is big and wide Chinese people made this, once they starting they make it great

1556:01
CAM-1 while we didn't finish read-back they said read back correct

1556:06
CAM-2 read-back?

1556:10
CAM-1 we didn't finish it last time

1556:14
CAM-2 we did

1556:30
CAM-1 the later part they interrupt

1556:38
CAM-2 yes again while our read-back they interrupt us

1557:22
CAM-1 yah there are so many airplanes in Shanghai airport I thought this airplane is Malaysian but it is China Eastern aircraft it makes me confused

1557:35
CAM-2 I think here is the base for China Eastern

1557:37
CAM-1 yes probably this is the home base for China Eastern

1557:39
CAM-1 here is so many airbus aircraft wow

1558:31
CAM-1 Shanghai ...

1558:41
CAM-1 Shanghai ...

1558:46
CAM-1 There is too much noise

1559:23
CAM-1 three six one eight it comes same as..

1600:01
CAM-1 tango zero is that direction tango zero
1600:07
TWR Korean Air six three one six confirm ready for departure.

1600:11
RDO-2 we are ready for departure Korean Air three six ah six three one six.

1600:15
TWR Korean Air six three one six line up and wait.

1500:18
RDO-2 line up and wait Korean Air six three one six.

1600:21
CAM-1 before take off checklist

1600:23
CAM-2 yes sir

1600:24
CAM-2 we can take this way

1600:26
CAM-1 here is tango

1600:28
CAM-1 they want us to go that way we suppose to go this way but..

1600:32
CAM-1 before take off checklist

1600:34
CAM-2 yes sir

1600:43
CAM-2 before takeoff checklist

1600:44
CAM-1 go ahead

1600:45
CAM-2 hi intensity wing and runway turn off landing light sir

1600:47 CAM-1 on

1600:50
CAM-2 hydraulic panel auto, air panel auto, EAD

1600:54
CAM-1 checked green box

1600:55
CAM-2 checked green box, before takeoff check's complete

1600:59
CAM-2 weather radar and transponder on

1601:28
TWR Korean Air six three one six clear for takeoff.

1601:30
RDO-2 clear for takeoff Korean Air six three one six.

1601:33
CAM-2 I am confirm cleared for takeoff

1601:35
CAM ((sound of increasing engine noise))

1601:39
CAM-1 auto-flight on

1601:41
CAM-2 auto-flight

1601:42
CAM-1 check thrust

1601:48
CAM-2 thrust is set
1601:55
CAM-2 eighty knots

1601:56
CAM-1 eighty

1602:06
CAM-2 vee one

1602:06
CAM-1 vee one roger

1602:08
CAM-2 rotate

1602:09
CAM-1 rotate

1602:18
CAM-2 positive climb

1602:19
CAM-1 gear up

1602:21
CAM ((sound of landing gear handle being raised))

1602:26
TWR Korean Air six three one six contact Shanghai tower one one eight correction contact Shanghai departure one one nine-oh [niner] seven five good day.

1602:28
CAM ((sound of auto-pilot trim tone))

1602:31
CAM ((sound of auto-pilot trim tone))

1602:33
CAM-1 left turn direct where?
1602:34 RDO-2
one oh nine three zero ah zero five one one one nineteen zero five Korean Air six six three one six?

1602:39
CAM-1 why this do not turn?

1602:40
TWR negative. one one nine-oh [niner] seven five.

1602:42
CAM ((sound of four auto-pilot disconnect warning warbler tones))

1602:44
CAM-2 okay Korean Air.

1602:45
CAWS auto-pilot (four auto-pilot voice))

1602:46
CAM-1 did you engage direct?

1602:47
CAM-2 yes

1602:51
DEP Korean Air six three one six now turn left direct to November Hotel Whiskey climb and maintain one thousand five hundred meters.

1602:52
CAM ((sound of altitude warning))

1602:53

CAWS altitude

1602:58
CAM-1 ah, here heading little ah ah

1602:59
RDO-2 okay direct hotel November, November hotel whiskey and say again altitude

1603:05
CAM-2 why this not work?

1603:06
CAM-1 make it turn, it doesn't turn, something's wrong with this airplane today

1602:08
CAM-2 okay let's turn

1602:08
DEP now turn left direct to November Hotel Whiskey climb and maintain one thousand five hundred meters.

1603:10
CAM-1 I don't see, where?

1603:13
CAM-2 yes, here keep turning left, keep turning left-

1603:15
CAM-1 keep turning? turning more

1603:15
CAM-2 and turning yes

1603:17
CAM-1 three thousand feet hold

1603:18
CAM-2 yes keep turning

1603:20
CAM-1 turning more?

1602:21
CAM-2 yes turning more

1603:22
CAM-1 ah shit

1603:23
CAM-1 altitude is increasing, but why november... is not showing

1603:26
CAM-2 turning more, turning more keep turning

1603:29
CAM-1 flaps up

1603:30
CAM-2 yes

1603:31
DEP Korean air six three one six climb maintain one thousand five hundred meters.

1603:35
RDO-2 one thousand five hundred meters Korean Air six three one six.

1603:37
CAM-1 It might turn upside down. what's wrong with this?

1603:40
DEP Korean Air six three one six left turn direct to November Hotel Whiskey.

1603:43
RDO-2 November ah November Hotel Whiskey Korean Air three six one six.

1603:45
CAM-2 thank you sir

1603:47
CAM-1 Are they asking us to?

1603:47
CAM-2 yes they are telling us to climb up climb up.

1603:52
CAM-1 okay engage nav

1603:52
CAM-2 yes

1603:53
CAM-1 ah why.

1603:54
CAM-2 slat why it doesn't work? slat, slat up

1603:58
CAM ((sound similar to flap handle being moved))

1604:03
CAM-1 ah sh

1604:04
CAM-2 yeah now it works, oh phew

1604:05
CAM-1 well what's wrong with this airplane today?

1604:07
CAM ((sound of altitude alert tone))

1604:07
CAWS altitude
1604:10

CAM-2 pitch sir

1604:11
CAM-1 uh oh look at this

1604:11
CAM-2 oh

1604:11
CAM ((sound of altitude alert tone))

1604:12
CAM-1 how far did they tell us to climb?

1604:13
CAWS altitude

1604:13
CAM-2 fifteen hundred feet

1604:14
CAM-1 ah ah oh

1604:15
CAM-2 fifteen hundred feet

1604:17
CAM-2 why isn't it working? Wait wait wait ah ah oh

1604:19
CAM-1 throttle throttle throttle

1604:19
CAM-1 just a moment just a moment uh

1604:20.2
CAM ((sound of whistle))

1604:20.3
CAM ((altitude alert tone))

1604:20.6
CAM ((sound of trim in motion tone))

1604:20.8
CAWS stabilizer motion

1604:21
CAM ((sound of rattling starts))

1604:22
CAM-2 wait wait, pitch...

1604:22
CAM-1 yah yah yah yah yah yah yah yah

1604:24
CAM ((sound of trim in motion tone))

11604:25
CAWS stabilizer motion

1604:26
CAM ((sound of rattling stops)

1604:29
CAM-1 unusual...

1604:27
CAM ((sound of altitude alert tone))

1604:28
CAM ((sound of trim in motion tone))

1604:28
CAWS stabilizer motion

1604:28

CAWS altitude

1604:28
CAM (sound of rattling starts)

1604:29
CAM-2 nose up nose up nose up

1604:30
CAWS stabilizer motion

1604:31
CAM-1 ah?

1604:31
GPWS terrain terrain

1604:32
CAM-2 nose up nose up nose up-

1604:33
GPWS woop woop pull up

1604:33
CAM-2 unable control nose up

1604:33.6
CAWS one thousand

1604:34
GPWS woop woop pull up

1604:35
end of recording

Appendix 7. Honeywell GPWS Analysis

REF: KAL-MD11
DATE: April 6, 2000
FROM: IL Auf Der Springe, Marc Calhoun

RE: KAL MD 11 Warning Scenario

A scenario has been developed based on the CVR data that was sent to us as two WAV fries by Alice Young-Masada on 4 April 2000. At the and of the audio we hear the following GPWS voices:

"Terrain Terrain-whoop whoop Pullup-whoop whoop Pullup". The start of the first terrain voice is approximately 3.9 seconds from the and of the audio.

The Terrain-Terrain voice was recognized to be a mode 2A alert. The subsequent Whoop-Whoop-Pull-Up voices could either be mode 1 or mode 2A warnings. Previous mention of a 2 second pause between Terrain -Terrain and Whoop-Whoop-Pull-Up could not be confirmed.

Using the 3.9 seconds of warning time until impact we have constructed a possible scenario for this warning. Understand that Mode 2 is a very dynamic mode, and the static warning curve does not always indicate exactly when a warning will occur. System time delays and filter time constants can cause the alerts to be given later than depicted in the specified 'static warning curves'. When the Mode 2 warning occurs depends on the following:

Radio Altitude Closure rate. If the Radio Altitude closure rate is the only varying parameter (level unaccelerated flight into terrain) then the mode operation can be depicted by the 'dynamic' mode curve published in the Product specification. This curve accommodates for system delays based on rate of descent. However these dynamic plots usually only depict closure rates of up to 10,000 FPM. We have measured the delays for faster rates. **Attachment 1** depicts the dynamic curve out to 40,000 FPM. If radio Altitude was the only varying parameter, then the 3.9 seconds of warning implies that the warnings started around 1,850 feet AGL. Please note that the GPWC does not use Pitch or Roll altitude to compensate the Radio Altitude value. In other words, as long as the data from the LRRA is valid, the GPWS uses the altitude reported to as is.

Baro Altitude Rate/Inertial Vertical Speed: Accelerating descent, based on the rate of change of vertical speed from the IRS, has the effect of advancing the mode 2 curve to increase warning times. So a downward acceleration, depending on its magnitude, will tend to cancel out some, but not all, of the dynamic warning delay described above.

Airspeed: The upper limit of the mode 2 curve itself is dependant on airspeed. If you assume fixed speeds of more than 310 knots, or less than 220 knots, then the curve is static. But if the speed is increasing between these values the curve itself is also increasing, which will have an affect on when the warning occurs.

So a simulation that just varies Radio Altitude to obtain a 3.9 second warning will not necessary reflect what actually happened. We have simulated several sets of dynamic conditions, where Radio Altitude, Vertical Speed and Airspeed are all varied to reflect accelerated flight towards level terrain. The conditions that produced a 3.9 second warning were as follows:

Vertical Speed: Increased linearly from 0 to -34,000 FPM. Note that due to ARINC 429 data scaling -32,768 FPM is the largest value the GPWS can see. That is why it limits out in the plot of **attachment 2**.

Radio Altitude: Staring at 5,000 feet AGL, accelerated to 0 feet matching the Vertical Speed changes.

Computed Airspeed: Increased linearly from 220 to 375 knots at impact.

Attachment 2 depicts these 3 dynamic inputs along with the warning occurrence. The simulation was run on a MKV, P/N 965-0976-021. We ran this scenario 3 times with the following results:

Run 1: Warning at 1940 Feet AGL (time to impact 3.8 seconds).
Run 2: Warning a~ 2007 feet AGL (time to impact 3.9 seconds, this is the run plotted in attachment 2).
Run 3: Warning at 1962 feet AOL (time to impact 3.8 seconds).

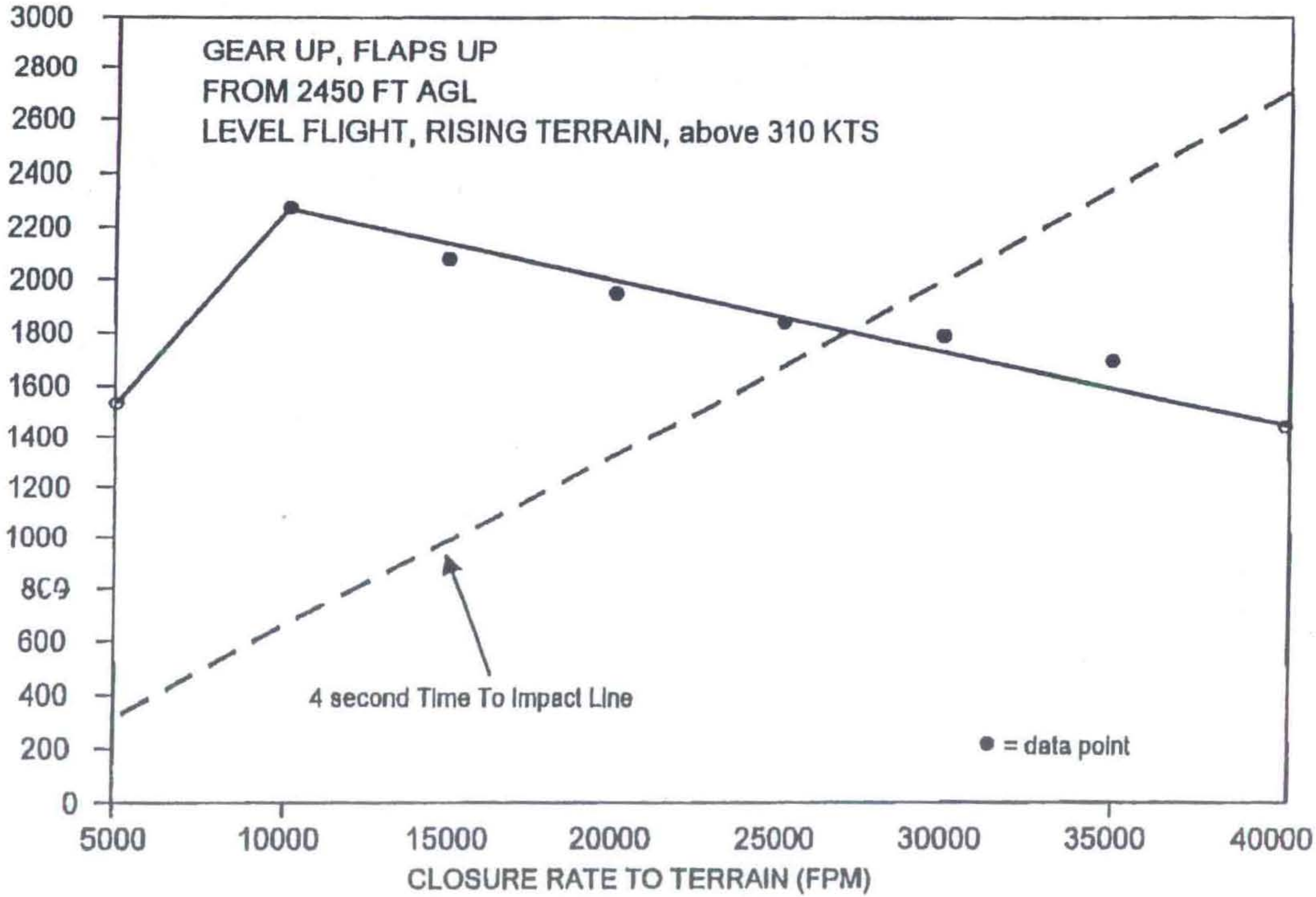
Mode 1 was also activated almost simultaneous to mode 2 in this scenario. But as the terrain voice has higher priority than "Sinkrate" it is not heard. **Attachment 3** provides the data used to generate the plot in tabular format.

Note: The acceleration that corresponds with the linearly increasing vertical speed of the final simulation was: 32.9f/s = 9.89 m/s

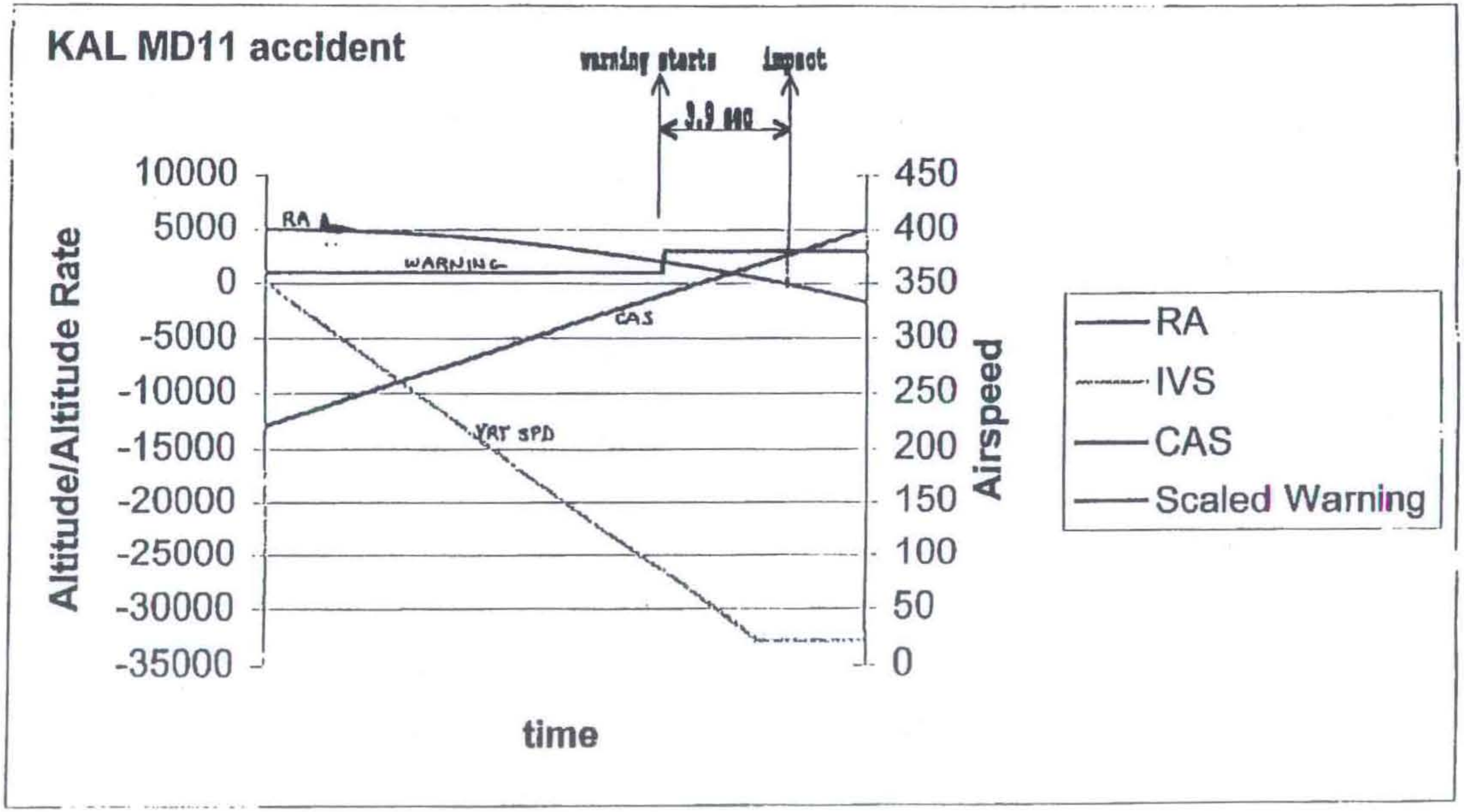
Time (roughly in seconds)	CAWS	pilot	GPWS
0	MOTION		
1	TONE		
2	ALTITUDE		
3		TRAYA?	
4		TRAYA?	
5		TRAYA?	
6	(GLIDESLOPE?)	TERA-TERA?	TERRAIN-TERRAIN
7		TERA-UH	WHOOP-WHOOP
8	(MANIFOLD?)	UNABLE CONTROL	PULL-UP
9		AIRPLANE	WHOOP-WHOOP
10			PULL-UP

Attachment 1 of Appendix 7:

MODE 2 DYNAMIC CURVE (level unaccelerated flight towards terrain)



Accelerated flight down at level terrain



Attachment 3 of Appendix 7: TABULAR RESULTS

Time (ms)	Rad Alt	IVS	CAS	WARNING
0	5000	0	220	0
2204	4999.38	-160	221.125	0
2305	4995.62	-400	222.25	0
2404	4997.38	-560	223.375	0
2504	4996	-800	223,375	0
2605	4994	-960	224.5	0
2704	4992	-1200	225.625	0
2805	4989.38	-1360	226.75	0
2905	4986.62	-1600	227.875	0
3005	4983.38	-1760	227.875	0
3105	4980	-2000	229	0
3204	4976	-2160	230,125	0
3304	4972	-2400	231.25	0
3409	4967,38	-2560	232.375	0
3504	4962.62	-2800	232.375	0
3605	4957.38	-2960	233.5	0
3705	4952	-3200	234.625	0
3804	4946	-3360	235.75	0
3905	4940	-3600	236.875	0
4004	4933.38	-3760	236.875	0
4105	4926.62	-4000	238	0
4205	4919.38	-4160	239.125	0
4305	4912	-4400	240.25	0
4405	4904	-4560	241.375	0
4505	4896	-4800	241.375	0
4604	4887.38	-4960	242.5	0
4705	4878.62	-5200	243.625	0
4804	4869.38	-5360	244.75	0
4905	4860	-5600	245.875	0
5005	4850	-5760	245.875	0
5104	4840	-6000	247	0
5205	4829.38	-6160	248.125	0
5305	4815.62	-6400	249.25	0
5405	4807.33	-6560	250.375	0
5505	4796	-6800	250.375	0
5604	4784	-6960	251.5	0

Time (ms)	Rad Alt	IVS	CAS	WARNING
5705	4772	-7200	252.625	0
5805	4759.38	-7360	253.75	0
5904	4746.62	-7600	254.875	0
6005	4733.38	-7760	254.875	0
6105	4720	-8000	256	0
6205	4706	-8160	257.125	0
6305	4692	-8400	258.25	0
6404	4677.38	-8560	259.375	0
6505	4662.62	-8800	259.375	0
6605	4647.38	-8960	260.5	0
6704	4632	-9200	261.625	0
6805	4616	-9360	262.75	0
6905	4600	-9600	263.875	0
7005	4583.38	-9760	263.875	0
7105	4583.62	-10000	265	0
7204	4549.38	-10160	266.125	0
7305	4532	-10400	267.25	0
7404	4514	-10560	268.375	0
7504	4496	-10800	268.375	0
7605	4477.38	-10960	269.5	0
7704	4458.62	-11200	270.625	0
7805	4439.38	-11360	271,75	0
7905	4420	-11600	272.875	0
8005	4400	-11760	272.875	0
8105	4380	-12000	274	0
8204	4359.38	-12180	275.125	0
8305	4338.62	-12400	276.25	0
8405	4317.98	-12560	277.375	0
8504	4296	-12800	277.375	0
8605	4274	-12960	278.5	0
8705	4252	-13200	279.625	0
8805	4229.38	-13360	290.75	0
8905	4206.62	-13600	281,875	0
9004	4183.38	-13760	281.875	0
9105	4160	-14000	283	0
9205	4136	-14160	284.125	0
9305	4112	-14400	285.25	0
9405	4087.38	-14560	286.375	0

Time(ms)	Rad Alt	IVS	CAS	WARNING
9505	4062.62	-14800	286.375	0
9604	4037.38	-14960	287.5	0
9705	4012	-15200	298.625	0
9805	3986	-15360	289.75	0
9905	3960	-15600	290.875	0
10005	3933.38	-15760	290.878	0
10104	3906.62	-16000	292	0
10205	3879.38	-16160	293.125	0
10305	3852	-16400	294.25	0
10405	3824	-16560	295.375	0
10505	3796	-16800	298.375	0
10604	3767.38	-16960	296.5	0
10705	3738.62	-17200	297.625	0
10805	3709.38	-17360	298.75	0
10905	3680	-17600	299.875	0
11005	3650	-17760	299.875	0
11105	3620	-18000	301	0
11205	3589.38	-18160	302.125	0
11305	3558.62	-18400	303.25	0
11405	3527.38	-18560	304.375	0
11505	3496	-18800	304.375	0
11604	3464	-18960	305.5	0
11704	3432	-19200	306.625	0
11805	3399.38	-19360	307.75	0
11904	3366.62	-19600	308.875	0
12005	3333.38	-19760	308.075	0
12105	3300	-20000	310	0
12204	3266	-20160	311.125	0
12305	3232	-20400	312.25	0
12404	197.38	-20560	313.375	0
12509	3152.62	-20800	313.375	0
12605	3127.38	-20960	314.5	0
12705	3092	-21200	315.625	0
12805	3056	-21360	316.75	0
12905	3020	-21600	317.875	0
13004	2983.38	-21760	317.878	0
13108	2946.62	-22000	319	0
13204	2909.38	-22160	20.125	0

Time(ms)	Rad Alt	IVS	CAS	WARNING
13304	2872	-22400	321.25	0
13405	2834	-22560	322.375	0
13504	2796	-22800	322.378	0
13605	2757.38	-22960	323.5	0
13705	2718.62	-23200	324.625	0
13805	2679.38	-23360	325.75	0
13905	2640	-23600	326.875	0
14004	2600	-23760	326.875	0
14105	2560	-24000	328	0
14205	2519.38	-24160	329.125	0
14304	2478.62	-24400	330.25	0
14405	2437.38	-24560	331.375	0
14505	2396	-24800	331.375	0
14604	2384	-24960	332.5	0
14705	2312	-25200	333.625	0
14804	2269.38	-28360	334.75	0
14905	2226.62	-25600	335.875	0
15005	2183.38	-25760	335.875	0
15104	2140	-26000	337	0
15205	2096	-26160	338.125	0
15305	2052	-26400	339.25	0
15405	2007.38	-26560	340.375	1
15505	1962.62	-26800	340.375	1
15604	1917.38	-26960	41.5	1
15705	1872	-27200	342.625	1
15805	1826	-27360	343.75	1
15908	1780	-27600	344.875	1
16005	1733.38	-27760	344.875	1
16105	1686.62	-28000	346	1
16205	1639.38	-28160	347.12	1
16305	1592	-28400	368.25	1
16405	·1844	-28560	349.375	1
16505	1496	-28800	349.375	1
16604	1447.38	-28960	350.5	1
16704	1399.62	-29200	51.625	1
16805	1349.38	-29360	352,75	1
16905	1300	-29600	353.875	1
17005	1250	-29760	353.875	1

Time(ms)	Rad Alt	IVS	CAS	WARNING
17105	1200	-30000	355	1
17204	1149.38	-30160	356.125	1
17305	1099.62	-30400	357.25	1
17404	1047.38	-30560	389.375	1
17504	996	-30800	358.375	1
17605	944	-30960	359.5	1
17705	892	-31200	360.625	1
17805	839.375	-31360	361.75	1
17905	786.625	-31600	362.875	1
18004	733.375	-31760	362.875	1
18105	680	-32000	364	1
18205	626	-32160	365.125	1
18304	572	-32400	366.25	1
18405	517.375	-32768	367.375	1
18605	407.375	-32768	368.5	1
18705	352	-32768	399.625	1
18804	296	-32748	370.75	1
18905	240	-32768	371.875	1
19004	183.375	-32768	371.875	1
19104	126,625	-32768	373	1
19205	69.375	-32768	374.125	1
19305	12	-32768	375.25	1

Appendix 8. Report on the Aileron and Rudder Actuator Examination by the NTSB

NATIONAL TRANSPORTATION SAFETY BOARD
Office of Aviation Safety
Washington, D.C. 20594

August 18,2000

AILERON AND RUDDER ACTUATOR EXAMINATION GROUP REPORT

A. ACCIDENT

Location	:	Shanghai, China
Date	:	April 15, 1999
Time	:	1607 local (0807 UTC)
Airplane	:	Boeing MD-11F, HL7373 Operated as Korean Airlines flight number 6316

B. SYSTEMS GROUP

Chairman: Richard B. Parker
National Transportation Safety Board
Washington, D.C.

Member: Alan W. Sinclair
Federal Aviation Administration
Los Angeles Aircraft Certification Office
Lakewood, California

Member: Anthony S. Rabano
Parker Aerospace Division
Parker Hannifin Corporation
Irvine, California

Member : David A. Hall
The Boeing Company
Long Beach, California

Member: Jinjoo Whang
The Boeing Company
Long Beach, California

C. SUMMARY

On April 15, 1999, at 0807 hours UTC, a Boeing MD-11F, HL7373, was destroyed when the aircraft entered a descent and impacted terrain in a residential area about 3 minutes after takeoff from Hongqiao Airport, Shanghai, China. The 3 flight crewmembers aboard the freighter aircraft and 7 persons on the ground were fatally injured and about 40 persons on the ground were injured. The aircraft, operated by Korean Airlines as flight 6316, was destined for Seoul, South Korea.

At the request of the Civil Aviation Authority of China, a group of party representatives was convened under the direction of the National Transportation Safety Board for the purpose of examining 6 flight control actuators. The actuators examined were the left-hand and right-hand outboard aileron actuators (2 each), the left-hand and right-hand inboard aileron actuators (2 each) and the upper and lower rudder actuators (2 each). The group was convened at the facilities of the actuator manufacturer, Parker Aerospace, in Irvine, California on July 24, 2000.

The actuators were received with substantial damage which precluded functional testing. Three manifold assemblies were present and 3 were absent. The 3 manifold assemblies present were for the left-hand outboard aileron actuator and the upper and lower rudder actuators.

D. COMPONENT IDENTIFICATION

Description: Outboard Aileron Actuator, Right-Hand
Manufacturer: Parker Aerospace, Irvine, California
Part Number: 338100-5007
Serial Number: 424

EXAMINATION

The manifold assembly was absent. The actuator was identified from the part number on the data plate. The actuator piston was extended 14.5 inches measured from the center of the actuator trunnion lug to the center of the rod end bearing. The rod end bearing housing was bent and the swivel ball was seized. The trunnion pillow blocks were absent as was the actuator end cover. The linear variable differential transformer (LVDT) was damaged and its associated circuitry as absent.

Internally, the piston shaft was bright, shiny and un-scored and was coated with an oily fluid resembling Skydrol. There was a modest amount of reddish residue resembling rust on the inner cylinder wall in vicinity of the piston positions. There were no circumferential impact marks observed on either the piston shaft or the inner cylinder walls and the shaft was visually straight. The Teflon seals and O-rings were intact..

E. COMPONENT IDENTIFICATION

Description: Outboard Aileron Actuator, Left-Hand
Manufacturer: Parker Aerospace, Irvine, California
Part Number: 338100-5003
Serial Number: unknown

EXAMINATION

The data plate was absent. The actuator was identified by the process of elimination from actuator "D" above.

The manifold assembly was separated from the actuator at the outboard attachments and was rotated approximately 30 degrees inboard. There were multiple impact or handling marks with several broken pieces of the casting body. The solenoid valves and the electro-hydraulic servo valves were intact, however, the main electrical connector was sheared off. The flight control actuator bellcrank was broken from the manifold casting. Internally, the manifold hydraulic ports were unprotected and the inlet screens were contaminated with debris resembling soil. The main hydraulic filter was clear. Mechanically, the internal linkage was intact and operated freely. The flight control input shaft operated freely and the autopilot lockout mechanism was intact.

The actuator piston was extended 12.6 inches measured from the center of the actuator trunnion lug to the center of the rod end bearing. The actuator LVDT assembly was bent and the actuator end cover was broken off at the attachment lugs. The actuator rod end was separated at the left and right sides of the end portion and the end cap and spherical bearing were absent. When viewed from the top of the actuator at the rod end, the actuator exhibited a slight bowed appearance to the right (inboard when installed on the aircraft) centered about the trunnions. Viewed in the same manner, there was a compression buckle visible in the right-hand (inboard) cylinder wall of the actuator about one-inch from the trunnion on the LVDT end. Internally, the piston shaft exhibited a bright, shiny appearance and was coated with an oily fluid resembling Skydrol. The Teflon seals and O-rings were visually intact. When viewed from the end, the piston rod was bent smoothly along its length about 2 or 3 degrees. There was a circumferential indentation mark located 2 inches from the LVDT end of the piston shaft. The mark extended over approximately 90 degrees of the shaft circumference and, during disassembly, it was noted that the score mark was radially aligned with the compression buckle on the cylinder wall. When the component parts of the actuator were laid out at their correct stations and the circumferential score mark was placed abeam the forward piston support gland, the piston shaft extension on the opposite end was approximately the same 12.6 inches measured above (trunnion to rod end).

F. COMPONENT IDENTIFICATION

Description: Inboard Aileron Actuator
Manufacturer: Parker Aerospace, Irvine, California
Part Number: 200900-5011
Serial Number: 0959

Note: Insufficient information was provided with items F and G to determine which was the left hand actuator and which was the right hand part.

EXAMINATION

The manifold assembly was absent. A data tag on the actuator body identified the unit serial number as 0959. The exterior surfaces of the actuator body exhibited rust type corrosion and there was no visible zinc chromate primer or surface plating visible as there was on the other 5 actuators. The actuator piston was extended 21.4 inches measured from the center of the actuator trunnion lug to the center of the rod end bearing. The piston shaft on the rod end side of the actuator exhibited a dull, bluish appearance and on the opposite (LVDT) end exhibited a bright, shiny appearance. The LVDT assembly was bent and broken and the actuator end cover was absent. The output end of the shaft was rotated 45 degrees clockwise when viewed from the rod end of the actuator. The trunnion pillow blocks were present and the trunnion bearings were seized. There was no detectable fluid in the piston chambers. The interior walls of both cylinders were corroded with a reddish substance resembling iron oxide corrosion (rust) and there was also a substance resembling fine silt soil. The Teflon seals and O-rings exhibited a melted appearance. After disassembly, the piston shaft exhibited a bluish appearance on the exposed portion near the rod end and was otherwise bright and shiny. After the reddish residue was chemically removed from the cylinder walls, there were no visible circumferential impact marks on the cylinder walls or piston shaft. The piston shaft was separated in 2 pieces at the O-ring groove under the piston on the LVDT end of the actuator, 8-inches from the end of the shaft.

G. COMPONENT IDENTIFICATION

Description: Inboard Aileron Actuator
Manufacturer: Parker Aerospace, Irvine, California
Part Number: 200900-5011
Serial Number: unknown

EXAMINATION

The manifold assembly was absent and there was no data plate. The unit was identified by exterior form. The actuator piston was extended 22.8 inches measured from the center of the actuator trunnion lug to the center of the rod end bearing. The trunnion and rod end bearings were free, however, the rod end was bent and the bearing was displaced. The rod end was rotated approximately 5 degrees clockwise when viewed from the rod end. The output piston shaft was visually bright and shiny. The LVDT was bent to the side and the associated wiring was damaged. The actuator end cover over the LVDT was absent. The interior walls of the cylinders were covered with a reddish residue resembling iron oxide corrosion (rust). The piston shaft was structurally intact as were the Teflon seals and O-rings. After chemically removing the reddish residue there were no visible circumferential impact marks on the cylinder walls or the piston shaft. Visually, the piston shaft was straight.

H. COMPONENT IDENTIFICATION

Description: Lower Rudder Actuator
Manufacturer: Parker Aerospace, Irvine, California
Part Number: 246700-1003
Serial Number: unknown

EXAMINATION

No data plate was present. The unit was identified by the process of elimination with item I below.

The manifold assembly was separated from the actuator and the securing bolts were sheared. The manifold housing exhibited multiple impact marks. The front mounting lug was broken and the lockout shroud was missing. All of the electrical solenoid valves and the electro-hydraulic servo valves were broken off. One autopilot LVDT was absent and the other 2 were bent. The hydraulic ports of the manifold were unprotected. The inlet screens were partially obstructed by a substance resembling soil and the servo slide was seized and contained a liquid resembling water and silt. Internally, the main hydraulic filter contained a reddish residue. The mechanical linkage and autopilot lockout mechanisms were intact although movement was impaired by the seized servo slide.

The actuator piston was extended 16.0 inches measured from the center of the actuator trunnion lug to the center of the rod end bearing. The piston rod end was rotated 70 degrees counter-clockwise viewed from the rod end. The piston shaft was bent on the LVDT end, however the rod surfaces were bright and shiny. The actuator end cover over the LVDT was absent and the LVDT was bent. The trunnion pillow blocks were absent. Approximately 3-inches of the piston shaft was absent on the LVDT end at the shoulder where the diameter decreases. Internally, the piston shaft exhibited a bright, shiny appearance and was coated with an oily fluid resembling Skydrol. The Teflon seals and O-rings were visually intact. There were 2 circumferential impact marks 7.8 and 9.0-inches from the shoulder where the piston shaft was separated. The circumferential impact mark extended over about 120 degrees radially, and, when viewed lengthwise, a 2 or 3-degree bend was present in the piston shaft in proximity of the circumferential marks. When the component parts of the actuator were laid out at their correct stations and the circumferential score mark was placed abeam the piston support gland, the piston shaft extension on the opposite end was approximately the same 16.0 inches measured above (trunnion to rod end).

I. COMPONENT IDENTIFICATION

Description: Upper Rudder Actuator
Manufacturer: Parker Aerospace, Irvine, California
Part Number: 202500-5011
Serial Number: 0583

Note: There was an identification mark vibra-etched onto the case of the manifold assembly, which read part number HT30189-2, serial number 2576

EXAMINATION

The unit was identified by data plates on the manifold assembly and actuator assembly.

The manifold assembly was separated from the actuator assembly and exhibited multiple impact marks. The aft mounting lugs were sheared and one of the center mounting lugs was broken out of the casting and the other was cracked around the perimeter. One solenoid valve was absent and the other 2 were damaged. The electro-hydraulic servo valve covers were absent and the valves were damaged. The hydraulic ports of the manifold were unprotected. The inlet screens were partially obstructed by a substance resembling soil . The main hydraulic filter contained a moderate amount of fine metallic particles. The servo slide, other mechanical linkage and the autopilot lockout mechanisms were intact and operated freely. The servo slide cavity contained an oily fluid resembling Skydrol and a dissimilar fluid resembling water.

The actuator piston was extended 12.2 inches measured from the center of the actuator trunnion lug to the center of the rod end bearing. The rod end bearing was free and the piston shaft was rotated approximately 10 degrees clockwise. The piston shaft was bright and shiny. The trunnion pillow blocks were absent. The LVDT shroud was broken at mid-length and the LVDT was bent to the side. The actuator piston shaft was visually straight and the Teflon seals and O-rings were undamaged. There were no circumferential impact marks on the piston shaft or the cylinder walls.

J. CONTROL SURFACE POSITIONS

The following aileron and rudder surface positions were calculated by the Boeing Company party representative based upon the actuator piston extension measured during the examination. The corresponding surface positions are calculated assuming the linear proportionality between the actuator stroke (travel) and the flight control surface travel.

SYSTEM	ACTUATOR LENGTH **(INCHES)**	SURFACE POSITION **(DEGREES)**	**REMARKS**
R/H O/B AILERON	14.5	20 deg TED*	Actuator at Max. Extended Length.
L/H O/B AILERON	12.6	0 deg	Actuator at Neutral
I/B AILERON (S/N 0959)	21.4	6 deg TED	
I/B AILERON (S/N UNKNOWN)	22.8	18 deg TED	
LOWER RUDDER	16.0	9 deg RIGHT	
UPPER RUDDER	12.2	24 deg LEFT	Designed Rudder Deflection is 23.5 Deg Max.

* TED = Trailing Edge Down

Richard B. Parker
Chairman

Appendix 9. Report on the Elevator PCU Disassembly and Examination by the NTSB

Korean Airlines MD-11 Flight No. 6316
Elevator PCU Disassembly and Examination
Field Notes

The disassembly and examination was held on July 11 to July 13, 2000 at Teijin Seiki America (TSA) in Redmond, Washington. In attendance were representatives of TSA, the U.S. NTSB, Boeing Commercial Airplane Group, and the FAA. Refer to the attached listing of attendees. All attendees participated in the disassembly and examination of the actuators. Prior to the disassembly of the actuators, a proposed agenda was presented. Refer to the attached agenda. TSA had no records of repairs or rework to the actuators.

The single packing crate was opened and the 4 actuators were found separated by scraps of cardboard. All 4 units were found severely damaged and no actuator level functional testing was deemed possible. Except as noted –

- All lockwire was found intact with raised "TS" on lead seals typical of those used by Teijin Seiki Japan (TSJ) during original manufacture.
- Red sealant application appeared consistent with other known TSJ examples.
- Contamination was found in the manifold inlet screens and main filters as detailed below in the Table 1, Contamination. Samples of the fluids and contaminants were taken for further examination.
- Serial numbers listed were those readable during the examination. Serial numbers not listed were not present (data plates missing) or were not readable.

Photographs were taken of the units as-received and an external measurement made of the as-received piston extension. Photographs were also taken of selected parts during the disassembly. All photos are identified as to the actuator S/N the part was removed from. To the extent possible, the actuators were disassembled using Teijin Seiki CMM procedures. The following are detailed observations for each actuator:

Left Inboard Actuator

Top Assembly – S/N unknown - data plate missing
Cylinder assembly P/N 1536440-3, S/N 0135 – MFG DATE DEC 91
Main Control Valve (MCV) – data plate missing
Electro Hydraulic Servo Valve (EHSV) S/N 4417
Solenoid #1 S/N 1194
Solenoid #2 S/N 1195
Main Ram LVDT S/N 1367
According to Boeing records, actuator serial number 0104 was installed on the left hand side at delivery. However, TSJ records for serial number 0104 do not match with any of the subassembly serial numbers found on this unit.

As received, the trunnion centerline to rod-end centerline dimension was measured to be 18.815" on the right side and 19.066" on the left side with the difference due to piston bending.

The control valve input arm was found against the stop closest to the rod end, but after applying less than one pound or force, the input arm moved by itself to a centered, neutral position, driven by internal springs.

The carriage assembly and summing lever were found fractured and the piston rotated approximately 180 degrees from the normal operating position. Material was ground away from both the housing and piston (carriage assembly end). The damage to both parts was in the same geometric plane with the piston in the as-found position.

The secondary piston shaft had a witness mark located 4.92" from the inner face of the piston surface that matched up with a land on the cylinder carriage end bearing. A review of the detail parts drawings indicates this is equivalent to a trunnion centerline to rod-end centerline dimension of 18.294".

After disassembly, the MCV was free to move normally against its springs. The autopilot mod piston was free to move.

The EHSV showed evidence of impact damage.

All of the damage and anomalies noted appeared consistent with impact damage with the exception of the internal contamination detailed in Table 1.

Right Inboard Actuator

Top Assembly – P/N 1536400-3 G, S/N 0027 (data plate missing)
Cylinder assembly – data plate missing
Main Control Valve (MCV) – P/N 1536470-1, S/N 0059
Electro Hydraulic Servo Valve (EHSV) S/N 4080
Solenoid #1 S/N A5984
Solenoid #2 S/N data plate missing

Note: The top assembly serial number was determined from TSJ records for S/N 0027 which listed sub-assembly serial numbers matching those found. According to Boeing records, this actuator was installed on the right hand side at delivery.

As received, the trunnion centerline to rod-end centerline dimension was measured to be 17.597" on the right side and 17.682" on the left side with the difference due to piston bending.

The input control arm stop nearest the rod end was broken and missing. The input arm was free to move and was found in the neutral position.

The solenoid #1 valve safety wire did not have any lead seals. The sealant used on this valve was white, all others used red sealant. Also, the serial number of this valve differed from that recorded in the original TSJ records.

The LVDT retaining nut was fractured.

The carriage assembly and summing lever were fractured and missing.

The secondary piston shaft had a witness mark located 4.84" from the inner face of the piston surface that matched up with a land on the cylinder carriage end bearing. A review of the detail parts drawings indicates this is equivalent to a trunnion centerline to rod-end centerline dimension of 18.21".

The main filter housing cap hex was sheared off, exposing the end of the filter. It is possible that contaminants entered by this path although the top of the filter tended to seal the resulting hole.

The EHSV showed evidence of impact damage.

After disassembly, the MCV was free to move normally against its springs. The autopilot mod piston was free to move.

All of the damage and anomalies noted appeared consistent with impact damage with the exception of the internal contamination detailed in Table 1.

Left Outboard Actuator

Top Assembly – P/N 1536500-51, S/N 0095
Cylinder assembly P/N 1536440-3, S/N 0096
Manifold package S/N 0086
Main Control Valve (MCV) – data plate missing
Electro Hydraulic Servo Valve (EHSV) S/N 4122
Solenoid #1 S/N A7424
Solenoid #2 S/N A7426

According to Boeing records, this actuator was installed on the left hand side at delivery.
As received, the trunnion centerline to rod-end centerline dimension was measured to be 14.868" on the right side and 15.361" on the left side with the difference due to piston bending.

The cylinder housing was split along the manufacturing break (bolts fractured). Both primary and secondary piston shafts were fractured near the carriage end cylinder end bearing. The rod end of the primary piston shaft and rod end bearing housing were bent.

No pillow blocks were present, however, one spherical bearing remains.

The control valve input linkage was fractured and the input arm could not be moved. It was found in position between neutral and one of the stops.

The carriage assembly and summing lever were fractured and missing.

The hydraulic tubes connecting the manifold to the cylinder were fractured.

The secondary piston shaft had a witness mark located 4.25" from the inner face of the piston surface that matched up with a land on the cylinder carriage end bearing. A review of the detail parts drawings indicates this is equivalent to a trunnion centerline to rod-end centerline dimension of 14.74".

After disassembly, the manifold leaked a large quantity of brown fluid resembling rusty water in appearance when handled. The MCV was seized due to corrosion in a position consistent with the input arm position. The input arm bearing was seized due to corrosion. After removal of the MCV and input arm bearing, the input crank was free to move. The autopilot lockout plunger spring shows a corrosion pattern consistent with puddled water. Remaining internal manifold components show rust-colored corrosion.

The EHSV showed evidence of impact damage.

All of the damage and anomalies noted appeared consistent with impact damage with the exception of the internal contamination detailed in Table 1.

Right Outboard Actuator

Top Assembly – P/N 1536500-51, S/N 0103
Cylinder assembly S/N 0103
Electro Hydraulic Servo Valve (EHSV) S/N 4117
Main Ram LVDT 1351

Table 1: Contamination

Actuator	Inlet/ Screen	Supplied by Airplane System	Metallic Dust	Metallic Shaving/ Slivers	Brown (dirt) Contaminant	Light (Peanut butter) Contaminant
LOB S/N0095	Main	1	Substantial		Slight	
	Inlet A	1		Several to 1/8"		None
	Inlet B	2				Substantial inlet port clogged
LOB CyIS/N0135	Main	2	Substantial			
	Inlet A	2		Several to 7/16"	None	Substantial
	Inlet B	3		Few, 1/16 to1/8" Max	Slight	1 Small piece
R/B S/N0027	Main	1	Substantial			
	Inlet ?	1or3		None	Substantial inlet port partial obstructed	None
	Inlet ?	1or 3		Few, small than 1/16"	Slight	None
ROB S/N0103	Main	2	Substantial			
	Inlet A	2		Several to 7/16"	Substantial inlet port clogged	Substantial
	Inlet B	1		Several to 1/4"	Substantial inlet port clogged	None

Supplement of Appendix 9

Korean Airlines MD-11 Flight No. 6316
Elevator PCU Disassembly and Examination
Field Notes - Supplement

This supplement adds the list of attendees, further information about the hydraulic fluid contamination found, and further information about one of the actuators.

Attendees:	Gregg Nesemeier	NTSB
	Christos Atalianis	NTSB observer
	Jim Erwin	FAA
	Kenneth Frey	FAA
	Ken Fairhurst	FAA
	Angelos Xidias	FAA
	Damon Pierce	Teijin Seiki America
	Byron Bakke	Teijin Seiki America
	Darrin Russell	Teijin Seiki America
	Simon Lie	Boeing

The disassembly and examination was held on July 11 to July 13, 2000 at Teijin Seiki America (TSA) in Redmond, Washington. In attendance were representatives of TSAK, the U.S. NTSB, Boeing Commercial Airplane Group, and the FAA. All attendees participated in the disassembly and examination of the actuators.

Hydraulic Fluid Contamination

Each actuator has two hydraulic inlet ports equipped with screens, one for Each of the two separate airplane hydraulic system's powering the actuator. in addition, each actuator has a much finer main filter downstream of the inlet screen on the primary system supplying the actuator in order to further protect the autopilot servo portion of the manifold. During the disassembly, hydraulic fluid contamination was found in all actuators. Several actuators had the hydraulic inlet ports packed with dirt. This material is identified as "Brown (dirt) Contamination" in Table 1. A different beige contaminant, the consistency of cured sealant was found in several inlet screens. This material, identified as "Light (peanut butter) Contamination" in Table 1, was found on the upstream side of the inlet screens. The debris present on 3 of the 8 screens obstructed a significant portion of the cross sectional area of the hydraulic lines at the screens. In addition, metal shavings and slivers were found in 7 of the 8 inlet screens, ranging in size up to 7/I6". With the exception of a few particles found in the main control valves, no shavings or large particles were found downstream of the inlet screens. Although care was taken, it is possible that the particles found in the main control valves may have been introduced during disassembly.

A fine metallic dust was found throughout the actuators, but was most noticeable on the main filters. Fluid samples taken from the area of the main filter contained sufficient metal dust for the fluid to appear as pearlized paint. The dust,, whether suspended in the fluid or by itself was not attracted to a magnet. A much smaller quantity of the metal dust appeared in fluid samples taken downstream of the main filter. Table 1 in the Field Notes provides details of the contamination found on the each actuator's inlet screens and filter.

Right inboard Actuator

Top Assembly - P/N 1536400-3 G, S/N 0027

The two metal keys installed to prevent rotation between the primary piston shaft and the redundant rod were missing. Although there was some damage to this area, a washer remained intact in such a position as to enable the washer to retain any keys that were present. The redundant rod had rotated relative to the piston shaft such that the keyways were out of alignment. The parts were found jammed in this position. There was no damage to indicate the keys had been sheared, nor were any fragments of the keys found. The relative rotation of the parts was in the direction to reduce the clamp-up torque on the assembly, but it did not appear that clamp-up was lost altogether. The Teijin Seiki America representatives present indicated that they did not believe the reduced clamp-up observed would significantly affect the operation of the actuator.

Further Examination

The main control valves were not disassembled due to lack of proper tools. The tools are now available and the main control valves are currently scheduled to be examined on 28-29 August 2000 at the same TSA facility.

The fluid and contamination samples were retained for examination at a later date.

Appendix 10. Report on the Elevator Actuator Solenoid Examination by the NTSB

Korean Airlines Flight No. 6316
Elevator Actuator Solenoid Examination
Field Notes

Examination of the autopilot engage solenoids was performed at the Boeing Equipment Quality Analysis (EQA) Laboratory, Seattle, WA, on August 30, 2000. Attendees at the examination were as follows:

Gregg Nesemeier	NTSB
Simon Lie	Boeing Air Safety Investigation
Damon Pierce	Teijin Seiki America
Dennis Baird	Parker (vendor – mfr. of solenoids)
Dave Carney	Parker
Dennis Bullock	Parker
Mike Colton	Boeing EQA
Ryck Whisler	Boeing EQA

The examination was conducted in the following sequence:

1. Each solenoid was located and removed from the elevator actuator box, identified as solenoid number 1 or 2 for the respective actuator where possible, tagged for identification, and digitally photographed as found.

2. Each actuator was placed in the EQA X-ray machine and X-rayed to determine the as-found position of the solenoid valve. Using the X-ray machine, digital images were taken of each solenoid overall and of the pressure seat (valve) position within each solenoid.

3. Following X-ray examination, each solenoid that was sufficiently intact was placed in a test block supplied by Mr. Baird, the Parker engineering representative, and checked for functionality. This check consisted of first measuring the electrical resistance in each of the two sets of coils within the solenoid, and then checking for actual operation of the solenoid with the unit under hydraulic pressure by measuring the output hydraulic pressure through the solenoid with a hydraulic test gauge. This step of the check was possible for 7 of the

8 solenoids (solenoid #2 of the right inboard actuator, MCV serial number 0059/top assembly serial number 0027, had its coils broken off and therefore could not be functionally tested).

Solenoids from actuator with main control valve serial number 0059 (top assembly serial number 0027), Right Inboard actuator:

Solenoid #1

Part No.: 205300-5005
Serial No: A5984

Unit found safety-wired.

X-ray shows pressure seat in closed (de-energized) position[1].

A/D coil resistance[2]: 58 Ω

B/C coil resistance: 738 kΩ

Function check: A/D coil operated solenoid properly at 1000 psi hydraulic pressure. B/C coil did not operate solenoid at 1000 psi hydraulic pressure. Operation at 3000 psi was not attempted on this solenoid.

Solenoid #2

Part No.: 205300-? (Unable to determine; data plate missing)
Serial No.: Unknown

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[1] The pressure seat (valve) consists of a disc which seats against two concentric rings when the valve is closed, and lifts away from the rings to open the valve. With the valve closed (solenoid de-energized), the disc can be seen in contact with the inner and outer rings on X-ray (the outer ring appears as two triangular shapes, one on each side of the central shaft; the disc contacts the upper point of the triangles when closed.) With the valve open (solenoid energized), a gap between the disc and the inner and outer rings would be observed. According to the Parker engineering representative, the valve utilizes hydraulic pressure to assist in closing during normal operation. However, a small internal spring, visible on X-ray on the opposite side of the disc from the inner and outer rings, exerts a small amount of force (1.2 lb) to push the valve closed.

[2] Each solenoid is equipped with two coils, either of which is capable of operating the solenoid independently. Electrical power to the coils is supplied through a 4-pin electrical connector, with the pins labeled alphabetically as A, B, C, and D. One coil is supplied power through pins A and D; the other coil is supplied power through pins B and C.

Unit found safety wired.

X-ray shows pressure seat in closed (de-energized) position.

Coils of this unit were broken off. No functional testing possible.

Solenoids from actuator top assembly serial number 0103 (Right Outboard actuator):

NOTE: Solenoids for this actuator were not identified as to which was #1 and which was #2. For differentiation purposes the solenoids were labeled solenoid A and solenoid B for this activity.

Solenoid A:

Part No.: 205300-5501
Serial No.: Unknown

Unit found safety wired. Seal with raised letters "BC" was in place.

X-ray shows pressure seat in closed (de-energized) position.

A/D coil resistance: 59.3 Ω

B/C coil resistance: 58.9 Ω

Function check: Both the A/D coil and the B/C coil operated the solenoid properly at 1000 psi and 3000 psi hydraulic pressure.

Solenoid B:

Part No.: Unknown
Serial No.: Unknown

Unit found safety wired. Seal with letter "C" was in place.

X-ray shows pressure seat in closed (de-energized) position.

A/D coil resistance: 58.0 Ω

B/C coil resistance: 58.5 Ω

Function check: Both the A/D coil and the B/C coil operated the solenoid properly at 1000 psi and 3000 psi hydraulic pressure.

<u>Solenoids from actuator top assembly serial number 0095 (Left Outboard actuator):</u>

<u>Solenoid #1</u>:

Part No.: 205300-5005
Serial No.: A7424

Unit found safety wired. A blank (unmarked) seal was in place.

X-ray shows pressure seat in closed (de-energized) position.

A/D coil resistance: 57.6 Ω

B/C coil resistance: 57.8 Ω

Some corrosion noted on pins. Mating connector well on manifold shows impact damage and is no longer round. Corrosion is also evident on manifold connector.

Function check: Both the A/D coil and the B/C coil operated the solenoid properly at 1000 psi and 3000 psi hydraulic pressure.

<u>Solenoid #2</u>:

Part No.: 205300-5005
Serial No.: A7426

Unit found safety wired. Seal with letters "BC" in place.

X-ray shows pressure seat in closed (de-energized) position.

A/D coil resistance: 59.0 Ω
B/C coil resistance: 59.1 Ω

Function check: Both the A/D coil and the B/C coil operated the solenoid properly at 1000 psi and 3000 psi hydraulic pressure.

Solenoids from actuator with cylinder serial number 0135 (Left Inboard actuator):

Solenoid #1:

Part No.: 881700-1001[3]
Serial No.: 1194

Unit found safety wired with letters "BC" on seal.

X-ray shows pressure seat in closed (de-energized) position.

A/D coil resistance: 60.1 Ω

B/C coil resistance: 59.7 Ω

Function check: Both the A/D coil and the B/C coil operated the solenoid properly at 1000 psi and 3000 psi hydraulic pressure.

Solenoid #2:

Part No.: 881700-1001
Serial No.: 1195

Coil area cover deformed and partially separated[4].

Unit found safety wired with letter "C" on seal.

X-ray shows pressure seat in closed (de-energized) position.

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[3] The Parker engineering representative indicated that part number 881700-1001 is Parker's current production unit, and is a newer application than the part number 205300-XXXX solenoids found on the other actuators.

A/D coil resistance: 59.6 Ω

B/C coil resistance: 59.8 Ω

Function check: At 1000 psi hydraulic pressure, both the A/D coil and the B/C coil operated the solenoid properly. At 3000 psi, both the A/D coil and the B/C coil operated the solenoid; however, leakage was noted from pressure to return when solenoid was energized, and cylinder pressure rose to only 2500 psi.

[1] The Parker engineering representative stated that the coil cover is a magnetic path for the solenoid, and that the solenoid may therefore not operate throughout its full designed range of travel with the coil cover in this condition.

Appendix 11. Report on the Analysis of Aileron and Rudder Actuator by the NTSB

NATIONAL TRANSPORTATION SAFETY BOARD

Office of Aviation Safety
Washington, D.C 20594
August 17, 2000

GROUP CHAIRMAN ANALYSIS REPORT
AILERON AND RUDDER ACTUATOR

A. ACCIDIENT

Location:	Shanghai, China
Date:	April 15, t999
Time:	1607 local (0807 UTC)
Aircraft:	Boeing MD-11F, HL7373
	Operated as Korean Airlines flight number 6316

B. DETAILS OF THE ANALYSIS

1. The piston displacement was measured, as received, and the control surface deflections calculated.
2. The actuators and manifold assemblies were disassembled and examined.

C. FINDINGS

1. The position of the actuator pistons and the corresponding control positions at impact are inconclusive. The piston positions may be indicative of the position at impact of the aircraft with the ground or they maybe the result of impact dynamics or they may be tile result of post-accident handling.
2. Two actuator shafts exhibited a circumferential score mark on the shaft. The left-hand outboard aileron actuator exhibited a mark at a displacement position corresponding to a neutral aileron. The lower rudder actuator exhibited 2 circumferential score marks at a displacement position corresponding to a 9 degree right rudder deflection.
3. The manifold assemblies (3 were present and 3 were absent) and the 6 actuators were substantially damaged which

precluded functional testing.

4. External and internal examination of the manifold assemblies and actuators did not reveal any indication of pre-impact: malfunction or failure.

D. PROBABLE CAUSE(S)

There were no findings to indicate that the actuators examined were contributory to the cause of the accident.

E. RECOMMENDATIONS

None

Richard B. Parker
Group Chairman

APPENDIX 12. Evaluation of data recovered from Korean Airlines MD-11 flight 6316 Electronic Engine Controls

1. ABSTRACT

This document provides a description of the data that were recovered from the Electrically Erasable Programmable Read Only Memory (EEPROM) of each channel contained within the Electronic Engine Control (EEC) units from Korean Airlines MD-11, registration HL73 73. This document also includes a description of the EEPROM features of the EEC, a description of the program used to interrogate the EEPROM, and an explanation of the printed EEPROM data.

2. BACKGROUND

On 15 April 1999, Korean Airlines flight 6316, a Pratt & Whitney powered MD-11 aircraft, was lost in an accident near Shanghai-Hongqiao Airport in Shanghai, China. Two of the recovered electronic engine control units from the three engines were returned to Hamilton Sundstrand, the manufacturer of the EEC's, for recovery of the data stored in the non-volatile memory (also known as EEPROM). The activity was accomplished in the presence of representatives from Pratt & Whitney, Hamilton Sundstrand, and the US National Transportation Safety Board.

3. SUMMARY

The EEC from engine # 1 was not recovered; thus, no data were available for this engine.

The EEPROM data from the Electronic Engine Control mounted on engine #2 were successfully recovered. A review of these data has revealed that channel A contained diagnostic messages that spanned 1,415 flight hours and 205 flight cycles; while channel B contained messages that spanned 736 flight hours and 110 flight cycles. Neither channel A nor channel B had recorded any messages for 181 flights prior to the terminal flight. On the terminal flight, no messages involving either channel A or channel B were recorded.

The EEPROM data from the Electronic Engine Control mounted on engine #3 were successfully recovered from channel A only, due to physical damage to Chip 4211 of channel B. A review of the recovered data revealed that channel A contained diagnostic messages that spanned 1,298 flight hours and 200 flight cycles. Channel A did not record any fault messages on the terminal flight, which was flight leg 201.

4. DESCRIPTIONS

4.1 Maintenance Data Storage System (EEPROM)

The maintenance data storage system consists of the following main elements:

- The logging of data that includes message diagnostic code, high-rotor speed (N2), engine inlet pressure (P2), aircraft mach number (MN), EEC internal temperature (TCJC), time of message entry, and engine run number on which the message occurred.
- The encoding of the diagnostic code from the 350 series maintenance words and the internal EEC detected discrepancies.
- The time keeping system which maintains EEC running time.
- The logging of flight leg which maintains EEC flight (or take-off) cycles.
- Tile logging of ground leg which maintains EEC ground (or non-flight) cycles.

The data logging within cells that consist of groups of 5 words containing the information shown in Figure 1. The four parametric bits of data(N2,P2, MN, and TCJC) have been selected to assist maintenance personnel in determining the environment in which the engine was operating at the time the message was recorded.

EEPROM message recording is enabled during engine operation. Encoding of the diagnostic message is a process that occurs shortly after the anomaly has been detected and transmitted via tile ARINC 350 words. The diagnostic codes are uniquely related to the 350 bits and are selected to allow for parity checking. All of the 350 bits can be stored in EEPROM. Ill addition to the encoded 350 words, detected anomalies that are internal to the EEC are also assigned a diagnostic code. EEC internal anomalies are not reported individually on the data bus but are grouped to form two bits identified as "EEC Channel Fault" or "EEC Unit Fault". "EEC Channel Fault" indicates an anomaly that can be isolated to an individual channel. "EEC Unit Fault" indicates an anomaly within tile EEC that could not be isolated to either channel. These codes are logged to assist maintenance personnel in determining the possible cause of EEC removal. Explicit requirements for fault recording are shown in Figure 2.

The time keeping system is designed to maintain an EEC and engine running time with a resolution of 20 minutes. The enable on the running time is analogous to that of EEPROM fault recording requirements, so that during ground test the control will not accumulate erroneous time.

The flight and ground leg counting sytem is also intended to assist maintenance personnel. By using the flight or ground leg reference, maintenance personnel can determine if the recorded anomaly occurred in the most recent flight or previous flights or if the anomaly occurred during a ground run. The counting will be indexed via logic shown in Figure 1. The flight and ground leg word stored at the time of the message is limited to 60,000. The determination of whether the message occurs during a flight leg or ground leg is based on MN, or if MN is failed, is based on altitude. The flight leg counter is incremented when MN exceeds 0.21 for the first time. If MN is failed, the counter is incremented when aircraft altitude exceeds 15,000 feet for the first time. The flight leg counter is only incremented once per EEC cycle. It is not incremented by an in-flight shutdown. The ground run counter is incremented as the engine is pressurized (external reset discrete is opened).

The EEC decides which run leg is stored with the message based on the criteria that updated the flight leg counter. If the message occurs before the flight leg counter is incremented, the ground run counter is stored. In order to identify ground data during playback, the P2 value at the time of the message is stored as a negative number. Once the flight leg counter is incremented, all subsequent messages are stored with the new flight leg number and a positive P2 value. Also, as the flight leg counter is updated, the ram buffer that records what messages have already been recorded is reset. This causes all messages that occurred during ground operation prior to take-off to be re-recorded as having occurred on the current flight leg.

4.2. P&W EEPROM Retrieval Program

The computer system that was used to extract the stored information from the EEC EEPROM chips consisted of an IBM compatible laptop computer, a Quatech DS-202 dual RS-422 interface, Pratt & Whitney fault retrieval software, a Pratt & Whitney bite/UART adapter cable, and a Pratt & Whitney UART/ARINC portable monitor cable.

The Pratt & Whitney message retrieval program ("Histry") downloaded the EEPROM of the two EEC channels, decoded the downloaded files, and generated a formatted report of the contents. For each stored message, Histry calculated values For ambient pressure (PAMB) and altitude (ALT) from the total pressure (P2) and Mach number (MN) information. Histry also inserted the word "ground" or "flight" in front of the printed leg number for each stored message. Histry based this decision on whether or not total pressure (P2) was stored as a negative or positive number. In both cases, the correct positive total pressure (P2) value was included in the printout.

The printout, listed in Appendix A, of the EEPROM for a channel of the PW4000 electronic engine control starts with a presentation of descriptive text that was input into the computer at the time the memory contents were downloaded.

The printout contains tile contents of the channel's EEPROM from cell I through cell 192. Tile printout contains a line of asterisk that divides the newest entry (which is above the line) from the oldest entry (which is below the line). Lines of dashes divide entries of different leg numbers. These leg numbers represent either a ground leg number or a light leg number depending on whether the condition occurred during ground running prior to a flight, or during a flight itself. For the purposes of message storage, a flight is considered to be over when the engine's fuel switch is placed in the cutoff position after landing.

Messages recorded by both EEC channels at the same time may not have the same leg counter shown. Leg counters of the two channels can diverge because they sometimes disagree on whether or not to increment a leg counter at a particular time. However, the elapsed engine run time values shown by the two channels for the same message should agree. This agreement provides a way to align the printouts for the two channels.

Following the listing of the cell contents, tile printout gives the value of the channel's latest flight leg counter value, ground leg counter value and elapsed engine time value. Also shown is the maximum cold junction compensation (TCJC) or internal EEC temperature seen by the channel as well as the time that maximum temperature occurred. Finally, the octal code for that channel's interpretation of the EEC DEM(programming plug) configuration is given.

The parametric data (N2, P2, MN, and TCJC) have a resolution determined by the weight of the least significant bit (LSB) with the chosen scale factor. The following resolutions apply:

Parameter	Resolution
N2	+ 128 rpm, - 0 rpm
P2	+ 0.25 psia, - 0.00 psia
MN	+ 0.008, - 0.000

TCJC + 0.004 °C, - 0.000°C

The parameters of ambient pressure (PAMB) and altitude (ALT) are calculated using the recorded P2 and MN values. Using the calculated PAMB value and relationships derived from Standard Atmosphere conditions, the fault retrieval program calculates the ALT parameter. The accuracy of both PAMB and ALT, which depends on the combination of resolutions of P2 and MN, is roughly 0.26 psi. and 500 feet, respectively. Since the ALT values are based on Standard Atmospheric conditions, corrections to the computed ALT must be made for non-standard atmospheric conditions that may exist at the time the fault message was recorded.

4.3. EEC Hardware Evaluation

Serial number 4000-0870 from engine #2 had one side of the housing crushed and the handle missing. Portions of wiring harnesses and connectors remained attached. A portion of the channel B wiring harness and sensor lines displayed soot and impact damage. Both processor boards were found in good condition, after the unit was split into two parts. The yellow seal on the housing showed that the last maintenance/update was completed in Singapore. The EEPROM chips 4212 and 4211 were de-soldered and removed in good condition from the channel A board. The channel B board was wet, with a connector lodged into the housing. Several wires required cutting in order to remove the board from the housing. Chips 4211 and 4212 were removed in good condition from the channel B board. The removed chips were installed into a test board and the faults extracted.

Serial number 4000-0803 from engine#3 had one side of the housing crushed with both channel A and channel B boards exposed and the handle missing. Several circuit board pieces were found in the shipping box. The unit was split into two parts. The Channel A board was damaged. The channel A chips, number 4212 and 4211, were de-soldered and removed in good condition. The channel B board was extensively damaged. Chip 4211 was found to be fractured in half, therefore, unreadable. Chip 4212 was removed and required several pins to be repaired. The channel A chips were installed on a test board and the faults extracted.

5. Fault Evaluation

The EEC from engine # 1 was not recovered; thus, no data were available for this engine.

The EEPROM data from the Electronic Engine Control (HS P/N: 791100-6-084, s/n: 4000-0870) of engine #2 were successfully recovered and printed (see Attachment A). This EEC utilized software version SCN5C. A review of the recovered data revealed that channel A contained diagnostic messages that spanned 1,415 flight hours and 205 flight cycles; while channel B contained messages that spanned 736 flight hours and 110 flight cycles. Neither channel A nor channel B had recorded any messages for 181 flights prior to the terminal flight. The terminal flight was labeled as flight leg 567 and the total elapsed engine time was recorded as 19,003.6 hours. The last fault was recorded on ground leg 646 at an elapsed time of 18,763 hours. No fault messages were recorded on either channel A or channel B during the terminal flight.

The EEPROM data from the Electronic Engine Control (HS P/N: 791100-6-096, s/n: 4000-0803) of channel A of engine #3 were successfully recovered and printed (see Attachment B). Damage to Chip 4211 prevented the recovery of data from channel B. This EEC utilized software version SCN6. A review of the recovered data revealed that channel A contained diagnostic messages that spanned 1,298 flight hours and 200 flight cycles. Channel A did not record any fault messages on the terminal flight, which was labeled as flight leg 201. The total elapsed engine time was recorded as 19,896.3 hours. The last fault was recorded oil flight leg 200 at an elapsed time of 19,895 hours. This fault was Fault #5: 'T350X - Opposite Channel wrote 350 Mnt Word'. Since no data were extracted from channel B, the fault that prompted the T305X fault recorded by channel A could not be determined. However, had a fault written to channel B been significant enough to affect dispatch status, channel A would also have also recorded the fault.

6. GLOSSARY OF TERMS

ACRONYM	DEFINITION
ADC	Air Data Computer
ALT	Altitude
ARINC	Aeronautical Radio, Inc.
BITE	Built In Test Equipment
DEM	Data Entry Modifier (also referred to as DEP. Data Entry Plug)
EEPROM	Electronically Erasable Read Only Memory (Also referred to as E2PROM)
FADEC	Full Authority Digital Electronic Control (Also referred

to as EEC)

LVDT	Linear Variable Differential Transformer
MN	Mach Number
N1	Low Pressure Rotor Speed (Fan Speed)
N2	High Pressure Rotor Speed
P2	Engine Inlet Total Pressure
PAMB	Pressure Ambient
REV	Reverser
T2	Engine Inlet Total Air Temperature
TCA	Turbine Cooling Air
TCJC	Temperature, Cold Junction Compensation (Thermocouple)
TRC	Thematic Rotor Control
UART	Universal Asynchronous Receiver Transmitter
VDC	Voltage DC
W/A	Wrap Around

Appendix 13. Report on the CVR addendum retrieval by the NTSB

FACTUAL REPORT OF INVESTIGATION
COCKPIT VOICE RECORDER

by

James R. Cash
Electronics Engineer

WARNING

The reader of this report is cautioned that the transcription of a CVR tape is not a precise science but is the best possible product from a NTSB group investigative effort. The transcript or parts thereof, if taken out of context can be misleading. Therefore, the attached CVR transcript should only be viewed as an investigative tool to be used in conjunction with other evidence. Conclusions or interpretations should not be made using the transcript as the sole source of information.

NATIONAL TRANSPORTATION SAFETY BOARD
Office of Research and Engineering
Washington, D.C. 20594

August 24, 2000

Group Chairman's Factual Report of Investigation

Cockpit Voice Recorder

DCA-99-RA-056

A. ACCIDENT

Location: Hongqiao Airport, Shanghai, China

Date: April 15, 1999

Time: 0804:59 Local Time

Aircraft: Korean Air McDonnell Douglas MD-11

B. GROUP

Chairman: James R. Cash
Electronics Engineer
National Transportation Safety Board

C. SUMMARY

A Fairchild model A-2000S cockpit voice recorder (CVR) s/n UNK was brought to the audio laboratory of the National Transportation Safety Board. A transcript was prepared of the last 22 minutes of the 2 hour fair[i] quality recording.

D. DETAILS OF INVESTIGATION

The Fairchild CVR that was installed on the accident aircraft was a 2-hour solid state recorder. This type of recorder has two operating modes that run at the same time. The first mode (mode-1) records the last 30 minutes of the cockpit conversations and it operates like a conventional normal quality 30-minute solid state or tape CVR recorder. CVR channel 1 is dedicated to the captain's hot microphone/radio/intercom selector panel. CVR channel 2 is dedicated to the co-pilot's hot microphone/radio/intercom selector panel. CVR channel 3 is normally connected to the 3rd officer's radio panel in a 3 crewmember aircraft. The last channel, CVR Channel 4, is dedicated to the cockpit area microphone.

The second operating mode (mode-2) records the information from time zero through time 120 minutes. This recording is organized to contain 2-channels of audio data. The first channel contains the area microphone information at a slightly reduced fidelity. The second channel is a summation of the information from the 3 hot microphone/radio/intercom channels.

The Fairchild A-2000S CVR recorder recovered from the accident aircraft sustained a severe amount of damage. The recorder's crash and fire protection enclosure was demolished. The internal circuit board that contained the solid state memory chips was reported to have been found just lying totally exposed in the wreckage. One of the memory chips was physically damaged. This memory chip was determined to be a total loss and was removed from the memory circuit board. The damaged chip contained some of the information from the first 30 minutes of the 4-channel recording (mode-1). The mode-2 recording, which uses other memory chips on the circuit board, was undamaged. The transcript developed was obtained by using the undamaged lower fidelity 2-hour (mode-2) recording

The 2-hour recording starts when the aircraft is on approach to the Hongqiao airport and continues during the landing and the ground operation and parking of the aircraft. When the recording starts again, the aircraft is in the process of being loaded for the accident flight. The recording continues uninterrupted from this point until the final impact at 0804:59 local time. The transcript starts at 0743:34 local time as the aircraft is getting ready for pushback from the gate. The transcript continues through engine start and taxi to runway 18: The flight was cleared for takeoff at 0801:52 local time. The transcript continues through the initial climb and ends with ground impact at 0804:59 local time

The inter-cockpit conversations between the two crewmembers were for the most part spoken in Korean. Only aircraft specific checklists and a few operational phrases between the crewmembers were spoken in English. All of the radio conversations to and from the aircraft to ground, tower and departure control were spoken in English.

During subsequent review of the transcript several changer were suggested. The review took place at the Boeing Aircraft Longbeach California facility on April 3-6, 2000. The following changes were suggested:

At time 0803:22, the sentence should be changed to read
CAM-1 ah, here heading little ah ah

At time 0803:37, add the word "yes" to the beginning of the statement.

At time 0804:01, change statement to read:
CAM-1 It might turn upside down, what's wrong with this

At time 0804:09, change statement to read:
CAM-2 Thank you sir.

At time 0804:11, change statement to read:
CAM-1 Are they asking us to?

At time 0804:11, change statement to read:
CAM-2 yes, they are telling us to climb up climb up

At time 0804:27, change statement to read:
CAM-1 ah sh—

At time 0804:28, add "oh phew" to the end of printed statement.

At time 0804:34 and 0804:35, correct order of statements to put 0804:34 before 0804:35 statement.

At time 0804:36, change statement to read:
CAM-1 how far did they tell us to climb?

At time 0804:38, change statement to read:
CAM-1 ah ah oh

At time 0804:41, change statement to read:
CAM-2 ah, why isn't it working, wait wait wait ah ah oh

At time 0804:46, change statement to read:
CAM-2 wait wait pitch

At time 0804:53, change statement to read:
CAM-2 nose up, nose up, nose up

At time 0804:55, change statement to read:
CAM-1 ah?

At time 080:56, change statement to read:
CAM-2 nose up, nose up, nose up

At time 0804:57, change the word "lift" to "nose"

The transcript was again reviewed in the Laboratory of the National Transportation Safety Board on June 6, 2000. The recording was examined by using a spectrum analysis program. This program makes it easier to pick out minute subtle details out of the CVR audio. Using this program, several corrections or additions were made to the original group transcript. The additions are as follows:

At time 0804:44, change time of statement CAM ((sound of whistle)) to be 0804:44.2

Add the following line at time 0804:44.3,
CAWS ((altitude alert tone))

At time 0804:44, change time of statement CAM ((sound of trim in motion tone)) to 0804:44.6

Add the following line at time 0804:44.8
CAWS stabilizer motion

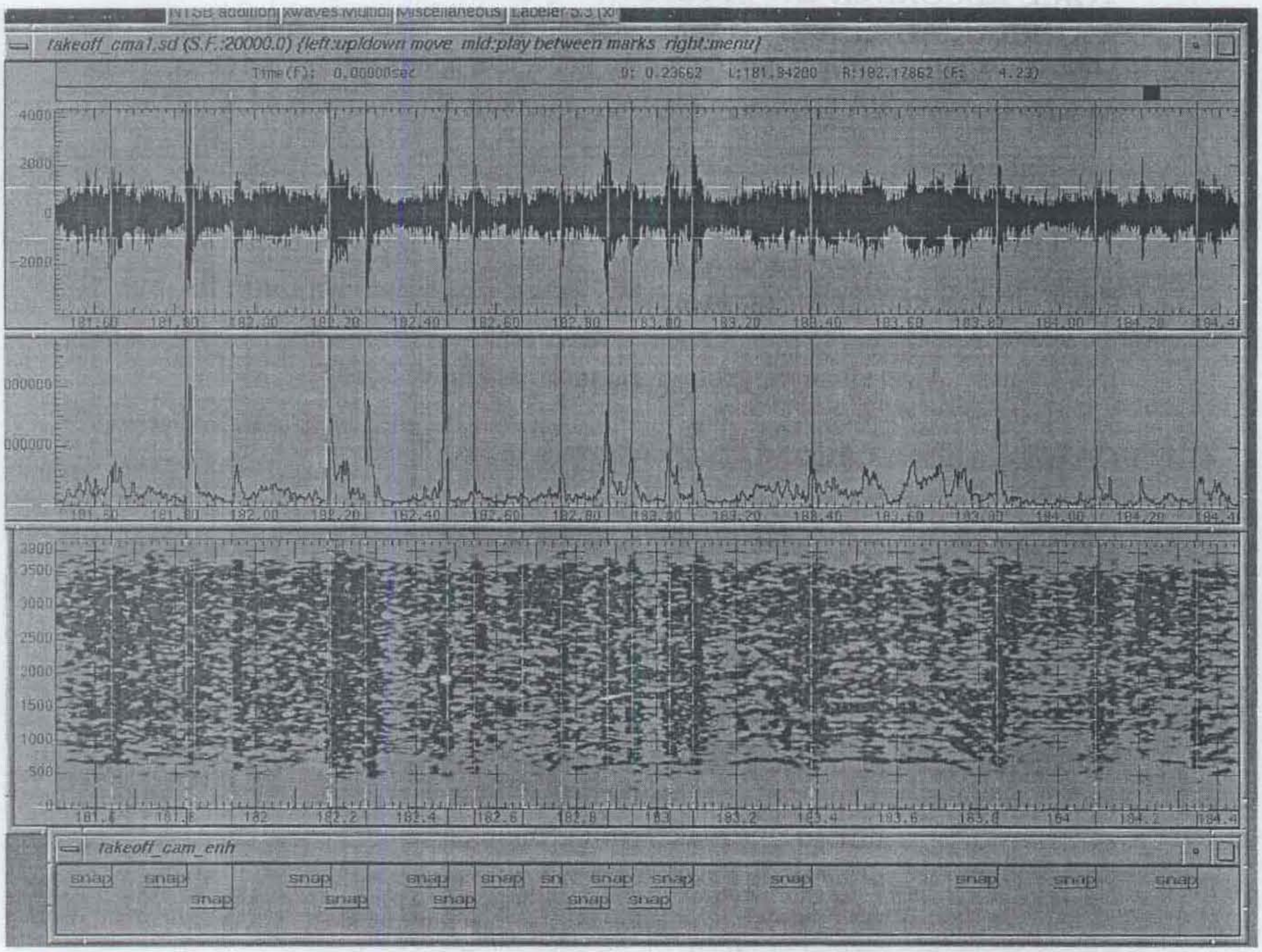
Add the following line at time 0804:57.6

CAWS one thousand

In addition to the above work the area on the recording that corresponded to the 0804:45 to 0804:50, which is characterized on the CVR transcript as the "sound of rattling" was examined. This five-second segment was examined in an attempt to determine the source of the rattling sound.

Chart 1 depicts this segment as recorded on the cockpit area microphone channel of the CVR recording. The top trace in the chart is the representation of the waveform of the signal. In this top trace, time in seconds, is along the horizontal axis and amplitude is depicted along the vertical axis. The middle trace is a depiction of the total energy of the signal shown in the top trace. Again time in seconds is along the horizontal axis and total energy is along the vertical axis. The bottom trace is a "voice print" or a spectrograph representation of the signal shown in the top trace. The spectrograph is a frequency representation of the signal where frequency in hertz is shown along the vertical axis. Intensity or amount of energy in a particular frequency is depicted by the various colors of the chart. Red being the highest energy followed by yellow and blue. The last trace is a text annotation of the various snap sounds that make up the rattling noise noted on the CVR transcript. It should be noted that the time shown on Chart 1 is an arbitrary CVR elapse time in seconds. For example, the voice signature noted at chart time 183 corresponds to the statement on the CVR transcript at time 0804:46.

CHART 1



It can be seen that the rattling noise consists for the most part of a repeating pattern of two snaps. The pairs of snaps are repeating at approximately a 10-Hertz rate over the 5-second period. This rate does not correspond to the stick shaker stall-warning rate, but it is more representative of a rattling dash or glare shield panel in the cockpit of the aircraft

James R. Cash

Electronics Engineer

TRANSCRIPT OF A FAIRCHILD 2-HOUR SOLID STATE COCKPIT VOICE RECORDER S/N UNKNOWN WHICH WAS REMOVED FROM A KOREAN AIRLINES, INC., McDONNELL DOUGLAS AIRCRAFT CO. MD-11, WHICH WAS INVOLVED IN AN TAKEOFF ACCIDENT ON APRIL 15,1999 AT THE HONGQIAO AIRPORT, SHANGHAI, CHINA

RDO	Radio transmission from accident aircraft
CAM	Cockpit Area Microphone sound or source
INT	Aircraft flight/ground intercom sound or source
CAWS	Aircraft Central Aural Warning System
GPWS	Aircraft Ground Proximity Warning System
-1	Voice identified as Captain (left seat)
-2	Voice identified as First Officer (right seat)
-3	Voice identified as Second Officer
-4	Voice identified as male aircraft ground personnel
-?	Voice unidentified
TWR	Hongqiao Local Controller (tower)
CLR	Hongqiao Clearance delivery
DEP	Hongqiao Departure Controller
UNK	Unknown source
*	Unintelligible word
@	Nonpertinent word
#	Expletive deleted

% Break in continuity

() Questionable text

(( )) Editorial insertion

\- Pause

Note: All times are expressed in local time. Only radio transmissions to and from the accident, aircraft were transcribed.

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[i] **CVR Quality Rating Scale**

The levels of recording quality are characterized by the following traits of the cockpit voice recorder information:

Excellent Quality	Virtually all of the crew conversations could be accurately and easily understood. The transcript that was developed may indicate only one or two words that were not intelligible. Any loss in the transcript is usually attributed to simultaneous cockpit/radio transmissions that obscure each other.
Good Quality	Most of the crew conversations could be accurately and easily understood. The transcript that was developed may indicate several words or phrases that were not intelligible. Any loss in the transcript can be attributed to minor technical deficiencies or momentary dropouts in the recording system or to a large number of simultaneous cockpit/radio transmissions that obscure each other.
Fair Quality	The majority of the crew conversations were intelligible. The transcript that was developed may indicate passages where conversations were unintelligible or fragmented. This type of recording is usually caused by cockpit noise that obscures portions of the voice signals or by a minor electrical or mechanical failure of the CVR system that distorts or obscures the audio information.
Poor Quality	Extraordinary means had to be used to make some of the crew conversations intelligible. The transcript that was developed may indicate fragmented phrases and conversations and may indicate extensive passages where conversations were missing or unintelligible. This type of recording is usually caused by a combination of a high cockpit noise level with a low voice signal (poor signal-to-noise ratio) or by a mechanical or electrical failure of the CVR system that severely distorts or obscures the audio information.
Unusable	Crew conversations may be discerned, but neither ordinary nor extraordinary means made it possible to develop a meaningful transcript of the conversations. This type of recording is usually caused by an almost total mechanical or electrical failure of the CVR system.