THE KINGDOM OF SAUDI ARABIA

GENERAL AUTHORITY OF CIVIL AVIATION

SAFETY AND ECONOMIC REGULATIONS

SAFETY DEPARTMENT

AIRCRAFT ACCIDENT REPORT

[redacted]

MD-11F, Registration [redacted]
King Khalid International Airport – Riyadh
Kingdom of Saudi Arabia

Abnormal Runway Contact (ARC)

15 Sha'aban 1431 H – 27 July 2010 G

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GLOSSARY

A	Alpha
AO	Aviation Occurrence
AP	Auto Pilot
APU	Auxiliary Power Unit
ARC	Abnormal Runway Contact
ASD	Aviation Safety Division
ATC	Air Traffic Control
ATPL	Airline Transport Pilot License
ATS	Auto Throttle System
BFU	Bundesstelle fur Flugunfalluntersuchung
CAC	Center Accessory Compartment
Cat	Category
C of G	Center of Gravity
CSMU	Crash Survival Memory Unit
CVR	Cockpit Voice Recorder
DFDR	Digital Flight Data Recorder
EFVS	Enhanced Flight Visibility System
FAA	Federal Aviation Agency
FCOM	Flight Crew Operating Manual
FLIR	Forward-Looking Infrared
FO	First Officer
FRS	Fire & Rescue Services
FS	Fuselage Station
GACA	General Authority of Civil Aviation
GACAR	General Authority of Civil Aviation Regulation
HPa	Hectopascals
ICAO	International Civil Aviation Organization
IIC	Investigator-In-Charge
ILS	Instrument Landing System
HPa	Hectopascal
HUD	Head-Up Display
IATA	International Air Transport Association
KKIA	King Khali International Airport – Riyadh
KSA	Kingdom of Saudi Arabia
L	Left
L1	Left one
LBA	Luftfart-Bundesamt
[redacted]	[redacted]
LSAS	Longitudinal Stability Augmentation System
[redacted]	[redacted]
MEL	Minimum Equipment List
METAR	Routine Aviation Meteorological Report
MTOW	Maximum Take-Off Weight
NTSB	National Transportation Safety Board
NOTAM	Notice to Airmen
PF	Pilot flying
PM	Pilot monitoring
PPE	Personal Protective Equipment
PRD	Pitch Rate Damping
QAR	Quick Access Recorder
QNH	Altimeter Setting
R	Right
SAR	Stand Alone Recommendation
S&ER	Safety and Economic Regulation
SD	Safety Department
TOW	Take-Off Weight
ULB	Underwater Locator Beacon
UTC	Coordinated Universal Time
VASI	Visual Approach Slope Indicator
VOR/DME	VHF Omni-directional Range/ Distance Measuring Equipment
Vref	Reference Approach Speed

agl	above ground level
asl	above sea level
°	degree(s)
° C	degree Celcius
θ	pitch angle
deg/sec.	degrees per seconds
ft	foot/feet
ft/min.	feet per minute
ft/sec.	feet per second
g	acceleration
h	hour
in.	inch(es)
kt	knot(s)
kg	kilogram(s)
lb	pound(s)
m	meter(s)
min.	minute(s)
nlf	normal load
nm	nautical mile(s)
no.	number
psi	pounds per square inch
sec.	second(s)
t	time
t	ton(s)
%	percent

INTRODUCTION

[redacted]
MD-11F, Registration [redacted]
King Khalid International Airport – Riyadh
Kingdom of Saudi Arabia

Abnormal Runway Contact (ARC)

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OBJECTIVE

In accordance with Annex 13 to the Convention on International Civil Aviation, it is not the purpose of aircraft accident investigation to apportion blame or liability. The sole objective of the investigation and the Final Report is the prevention of accidents and incidents.

Unless otherwise indicated, recommendations in this report are addressed to the regulatory authorities of the State having responsibility for the matters with which the recommendations are concerned. It is for those authorities to decide what action is to be taken.

CONDUCT OF THE INVESTIGATION

The Aviation Safety Division (ASD) of the General Authority of Civil Aviation (GACA) was notified of this accident at 11h45[1] on the same day. The ASD immediately instituted an investigation and notified Germany and the United States of America through their respective Investigation Authorities. The International Civil Aviation Organization (ICAO) was also notified. The ASD formed an investigation team consisting of an Investigator-In-Charge/Operations Specialist, a Technical Investigator and an ATS Investigator. This ASD team travelled to Riyadh on the same day.

In the days that followed, the following teams joined the investigation: [redacted] representing the operator, the Accredited Representative and his Advisers from the German Federal Bureau of Aircraft Accident

1. Unless otherwise indicated, all times in this report are local time. Local time in the Kingdom of Saudi Arabia is Coordinated Universal Time (UTC) plus three (3) hours.

Investigation – the Bundesstelle fur Flugunfalluntersuchung (BFU) representing the State of Registry and the State of the Operator and, the Accredited Representative and his Advisers from the National Transportation Safety Board (NTSB) representing the State of Manufacture and the State of Design.

The site investigation was carried out in a professional manner by all participants in accordance with the Standards and Recommended Practices of ICAO Annex 13. Also, the support from the President's Office of the GACA and the full cooperation of all the Departments of the King Khalid International Airport – Riyadh, under the leadership of its Acting Airport Director General greatly facilitated the work of the investigation team.

The post-site investigation took place over a period of ten (10) months. During this period, the Investigator-In-Charge (IIC) and the Accredited Representatives of the BFU and the NTSB had several teleconferences where many aspects of the investigation were discussed. Studies were also conducted during this period.

On 30 May 2011, the Safety Department (SD) of the GACA/S&ER agreed to the issuance of two (2) Stand Alone Recommendations (SAR) by the NTSB to the Federal Aviation Agency (FAA). Those 2 SARs were issued by the NTSB on 12 July 2011.

On 04 July 2011, the SD of the GACA/S&ER sent, via the Internet, the Draft Final Report to the BFU and the NTSB for comments. Those Investigation Authorities were authorized to share a copy of the Draft Final Report, respectively with [redacted] and the Boeing Aircraft Company for their comments. All were given sixty (60) days, that is until 03 September 2011 to provide the SD of the GACA/S&ER with their pertinent and substantiated comments on the Draft Final Report. The comments from all four (4) parties were received prior to 03 September 2011. In the weeks that followed, the pertinent and substantiated comments were included in the Final Report.

Following the internal GACA/S&ER reviews, the Final Report was approved by the Board of Directors of the GACA on 21 January 2012.

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SYNOPSIS

The MD-11F was on a flight from Frankfurt, Germany to Riyadh, Saudi Arabia. During the landing phase on runway 33Left in Riyadh, the MD-11F bounced during the initial firm landing, which was followed by two (2) hard landings. The aft fuselage ruptured and the aircraft eventually stopped to the left of the runway following the collapse of the nose gear. A fire occurred in the area of the ruptured fuselage, which consumed a great portion of the fuselage and the cargo.

The proper landing technique and the bounce recovery technique were not applied. The aircraft was destroyed. The First Officer sustained serious injuries.

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1.0 FACTUAL INFORMATION

1.1 History of the Flight

On 27 July 2010, [redacted] Flight [redacted] [redacted]) was scheduled to depart from the Frankfurt International Airport, Germany at 01h00 UTC for a cargo flight to the King Khalid International Airport – Riyadh, Kingdom of Saudi Arabia (KSA).

The departure was delayed by more than two (2) hours due to water in the Centre Accessory Compartment (CAC). [redacted] departed Frankfurt at 03h32 UTC with 79,247 kilograms (kg) of cargo including dangerous goods. The take-off weight (TOW) was 248,307 kg. There were 2 flight crew members on board. The First Officer (FO) was the Pilot Flying (PF) and the Captain was the Pilot Monitoring (PM).

This flight was the first time this Captain and First Officer (FO) were flying together. The FO had been employed by [redacted] for seven (7) months. The Captain decided that the FO would be the PF, as the FO had not flown into Riyadh before and it would be an appropriate leg for him to fly.

En-route to Riyadh at cruising altitude, both flight crew members took advantage of the company napping policy, where each had about thirty (30) minutes of sleep while remaining in their respective seat. The en-route portion of the flight was uneventful.

During the approach to Riyadh , [redacted] was radar vectored for an Instrument Landing System (ILS) approach for runway 33 Left (33L). With flaps at 35 degrees (°) and a landing weight of 207 tons (t), the Reference Approach Speed (Vref) was determined as 158 knots (kt). The Auto Pilot (AP) and the Auto Throttle System (ATS) had been turned OFF by the FO. The surface winds were from 340° at 14 kt and the temperature was + 39°Celcius (°C).

The aircraft was centered on the glide slope and localizer during the approach, until 25 seconds (sec.) before touchdown when it dipped by half a dot below the glide slope. During that period, the indicated airspeed oscillated between 160 and 170 kt, centered about 166 kt. The ground speed was 164 kt until 20 sec. prior to touchdown, when it began to increase and reached 176 kt at touchdown.

The flare was initiated by the FO between 1.7 and 2.0 sec. before touchdown, that is: 23 to 31 feet (ft) above the runway. The main gear touchdown took place at 945 ft from the runway threshold at a descent rate of -13 ft/sec. (780 ft/min) resulting in a normal load factor (*nlf*) of 2.1g. The aircraft bounced with the main gear reaching a maximum height of 4ft above the runway with the spoilers deployed to 30° following main-wheel spin up. During this bounce, the Captain who was the Pilot Monitoring (PM) pushed on the control column resulting in an unloading of the aircraft. The aircraft touched down a second time in a flat pitch attitude with both the main gear and nose gear contacting the runway, at a descent rate of -11 ft/sec. (660 ft/min), achieving a *nlf* of 3.0g.

Just prior to this second touchdown, both pilots pulled on the control column, which combined with the rebound of the nose gear from the runway, resulted in a 14° pitch angle during the second bounce. Additionally, the spoilers reached their full extension of 60° following the compression of the nose gear strut during the second touchdown. During this second bounce, the main gear reached a height of 12 ft above the runway. Early in this second bounce, the Captain pushed the control column to its forward limit and the elevators responded accordingly.

Prior to the third and final touchdown, both pilots pulled back on the control column at slightly different times. Although the elevators responded accordingly and started to reduce the nose-down pitch rate, the aircraft was still pitching down at the third touchdown. During this third touchdown, the aircraft contacted the runway at a descent rate of -17 ft/sec (1020 ft/min), thus achieving a *nlf* of 4.4g. At this point, the aft fuselage ruptured behind the wing trailing edge. Two (2) fuel lines, one (1) fuel line to the number (no.) 2 engine/Auxiliary Power Unit (APU) and, a transfer line to the tail fuel tank were severed and fuel spilled within the left hand wheel well. A fire ignited and travelled to the upper cargo area.

The Captain attempted to maintain control of the aircraft within the runway boundaries. Not knowing about the aft fuselage being ruptured and dragging on the runway, the Captain deployed the engine thrust reversers, but only the no. one (1) and the no. three (3) engines responded. The Captain maintained directional control of the aircraft as best he could and requested the F/O to declare a Mayday.

The aircraft then went towards the left side of the runway as the Captain attempted, without success, to maintain the aircraft on the runway. As the aircraft departed the runway, the nose gear collapsed and the aircraft came to a full stop 8800 ft from the threshold of the runway and 300 ft left from the runway centerline (Figure 3 – Appendix C).

The fuel to the engines was cut off and both pilots evacuated the aircraft by using the slide at the Left One (L1) door. The mid portion of the aircraft was on fire. Vehicles from the Fire and Rescue Services (FRS) arrived at the aircraft within a very short period of time. Both pilots were taken to the hospital and the fire was eventually extinguished.

The accident occurred at 11h38 local (08h38 UTC) on runway 33L at the King Kalid International Airport – Riyadh, Kingdom of Saudi Arabia.

1.2 Injuries to Persons

Injuries	Crew	Passengers	Total	Others
Fatal	0	0	0	0
Serious	1	0	1	0
Minor	1	0	1	0
None	0	0	0	0
Total	2	0	2	0

1.3 Damage to Aircraft

The aircraft was destroyed.

1.4 Other Damage

There was some damage to the surface of runway 33L.

1.5 Personnel

1.5.1 The Captain

1.5.1.1 General

The Captain was a German national employed by [redacted]. During this flight, the Captain was the Pilot Monitoring (PM).

1.5.1.2 Qualifications

The Captain held a German Airline Transport Pilot License (ATPL), Number 33110089015 issued on 21 August 1996, which was valid until 19 May 2015. He held type ratings as follows: MD11 PIC and IR Cat III valid until 11 June 2011, SE piston PIC and IR and, motor glider.

The Captain held a valid First Class Medical Certificate issued on 26 April 2010, which was valid until 26 May 2011. The medical certificate contained no limitations.

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1.5.1.3 Flying experience

Total Flying Hours	8270
Total hours on Type	4466
Hours On Type as Captain	1327
Hours on Type Last 12 Months	483
Hours on Type Last 90 Days	127
Hours on Type Last 30 Days	38
Hours on Type Last 7 Days	7
Hours on Type Last 24 Hours	5
MD-11 Landings – Last 30 Days	3
MD-11 Landings – Last 7 Days	1
Hours of rest prior to duty	24 +

1.5.1.4 MD-11 Training

The Captain initial and most recent training were as follows:

Initial Training	Date Completed
CM-1a Phase Qualification (simulator)	29 July 2008
CM-1b Phase Qualification	14 August 2008
Leadership Phase	16 September 2008
Confidence Phase	25 September 2008
Final Line Check	02 October 2008
Proficiency/Skill Test	10 June 2008

Recent Training	Date Completed
Simulator Refresher	01 March 2010
CRM Class	08 June 2010
Proficiency Check	10 June 2010

No bounce landing training was performed during the last simulator refresher on 10 June 2010. The last bounce landing training took place in 2008.

1.5.1.5 Captain's Record

According to the Luftfahrt-Bundesamt (LBA) of Germany, the Captain had no record of accidents, incidents or violations.

1.5.1.6 Control inputs

The Captain did not indicate at any time to the FO that he was taking control of the aircraft. The Captain recalled the first touchdown and the period following the second bounce. Specifically, he recalled his surprise at the high pitch angle achieved and his response of pushing, neutralizing and then pulling on the control column to prevent the aircraft from slamming onto the runway as the nose of the aircraft was coming down prior to the third touchdown.

The Captain did not recall his previous inputs on the control column, including his push on the control column after the first touchdown and his pull on the control column just prior to the second touchdown.

1.5.2 The First Officer

1.5.2.1 General

The First Officer (FO) was a German national employed by [redacted]. During this flight, the FO was the Pilot Flying (PF).

1.5.2.2 Qualifications

The FO held a German Airline Transport Pilot License (ATPL), Number [redacted] issued on 27 November 2003, which was valid until 11 November 2011. He held type ratings as follows: MD-11 and IR Cat III valid until 31 March 2011.

The FO held a valid First Class Medical Certificate issued on 15 December 2009. The medical certificate contained no limitations.

1.5.2.3 Flying experience

The FO had previously flown the Airbus 319 with [redacted] as 1st officer, from 01 August 2005 to 01 February 2010.

The FO had made eighteen (18) landings on the MD-11F as PF. Most of these landings were made at airports at or near sea level. Three (3) landings were made at Sharja, UAE on 30 March 2010. During his training, the FO made two (2) landings at high elevation airports. From 20 May to 21 July 2010, the FO made eight (8) landings as PF. This landing was the first at KKIA-Riyadh.

The FO indicated that the Airbus 319 stick could be handled with only three (3) fingers and little force, while the MD-11F required greater force and two (2) hands on the control column.

Total Flying Hours	3444
Total hours on Type	219
Hours On Type as Captain	0
Hours on Airbus 319 – 1^{st} officer	2957
Hours on Type Last 90 Days	219
Hours on Type Last 30 Days	37
Hours on Type Last 7 Days	14
Hours on Type Last 24 Hours	5
MD-11 Landings – Last 30 Days	3
MD-11 Landings – Last 7 Days	1
Hours of rest prior to duty	24+

1.5.2.4 MD-11 Training

The FO initial and most recent training were as follows:

Initial/Recent Training	Date Completed
CRM Class	16 February 2010
Phase I Normal Qualification (simulator)	23 February 2010
Phase II Flying Skills Qualification (simulator)	28 February 2010
Phase III Abnormal Emergency Qualification (simulator)	07 March 2010
Phase IV Abnormal Emergency Qualification (simulator)	12 March 2010
Phase V Interpersonal Qualification (simulator)	18 March 2010
Phase VI Final Qualification (simulator)	22 March 2010
Landing Training (simulator)	25 March 2010
Skill Test/Proficiency Check (simulator)	26 March 2010
Initial Aircraft Landings	30 March 2010
Final Check	13 May 2010
Line Check	18 May 2010

The FO made seventeen (17) landings in the simulator during Phase VI. In general, grading and comments on the FO's training were satisfactory and training progress was normal, except for additional landing training. This training took place prior to the skill test, which was the initial proficiency check on the aircraft. The FO was provided with two (2) additional simulator training periods. During these periods, the FO recorded a total of twenty-eight (28) landings.

1.5.2.5 FO's Record

According to the Luftfahrt-Bundesamt (LBA) of Germany, the FO had no record of accidents, incidents or violations.

1.5.2.6 Control inputs

The FO recalled that at about 80 ft on the radar altimeter, he sensed a sinking or increased sinking of the aircraft. The FO indicated that he either added power or delayed retarding the power and he initiated the flare between 30-40 ft above the runway. During the flare, he lowered the nose slightly.

The FO did not have a clear recollection of what took place or of his actions following the first touchdown, nor when the Captain took over control of the aircraft. He recalled the Captain directing him to declare a Mayday. The Mayday call was delayed until the aircraft departed the runway, as the FO had to reach to the floor to recover his headset and mike.

1.6 Aircraft Information

Aircraft Manufacturer	McDonnell Douglas - Boeing Aircraft
Year of Manufacture	1993
Type & Model	MD-11F
Nationality	German
Serial Number	48431/534
Registration	D-A[redacted]
Certificate of Airworthiness	Valid
Total Hours	73247
Total Cycles	10073
Maximum Take-off Weight	285,990 kg
Engine Manufacturer	General Electric
Engine Type & Model	CF6-80C2

This aircraft was originally delivered as a passenger aircraft in 1993. In 2004, it was converted to a freighter configuration and had been operated by [redacted] since 15 November 2004.

The last C-check was accomplished on 22 June 2009 with 68283 FH. An "A-Additional + 4A + R1" check was accomplished on 26 July 2010. There was one (1) listed item on the Minimum Equipment List (MEL); it was for the right hand logo light which was inoperative.

This MD-11F was properly certificated and had been maintained in accordance with approved procedures.

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1.7 Meteorological Information

The forecast for KKIA-Riyadh used by the flight crew prior to departure from Frankfurt, Germany was issued at 22h00 UTC on 26 July 2010. This forecast indicated winds to be from 320° at 10 kt, becoming 360° at 16 kt.

The routine aviation meteorological report (METAR) valid for the KKIA-Riyadh airport at 11h00 local (08h00 UTC) reported: Surface winds of 340° at 14 kt, visibility and clouds CAVOK, temperature 34°C, the dew point 06°C, and QNH setting 1006 Hectopascals (HPa). The conditions were similar during the approach and landing of [redacted], except that the temperature was 39°C. At this temperature, the density altitude in the vicinity of runway 33L was about 5300 ft.

1.8 Aids to Navigation

On 27 July 2010, all approach aids and runway lights for runway 33L were reported as functioning properly. Runway 33L was equipped with an ILS Cat I, a VHF Omni-directional Range equipped with Distance Measuring Equipment (VOR/DME) and a Visual Approach Slope Indicator (VASI) 3 bar 16 unit with a 3° glide slope. No problem or anomaly with those approach aids were reported by the flight crew of [redacted] or other flight crews having used the same facilities.

In the early days of the site investigation, a flight check of the approach aids (ILS, VOR/DME and VASI) for runway 33L in Riyadh was requested. The flight check of those approach aids was conducted on 14 August 2010. The results were as follows:

- The ILS system parameters were within ICAO prescribed tolerance limits for CAT I operations;
- The VOR/DME performance for Standard Approach Procedures were satisfactory; and
- The VASI lights needed adjustment to coincide with the ILS Glide Path.

A Notice to Airmen (NOTAM) was issued on 24 August 2010 advising pilots that runway 33L VASI was not aligned with the ILS Glide Path and should not be used.

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1.9 Communications

All communications between [redacted] and the Riyadh ATC controllers were clear and well understood.

1.10 Aerodrome Information

1.10.1 General

The King Khalid International Airport – Riyadh has two (2) parallel runways: 15 Left (L)/33 Right (R) and 15R/33L. Both runways are covered with asphalt. The airport elevation is 2049 ft above sea level (asl). The accident occurred on runway 33L (Figure 1).

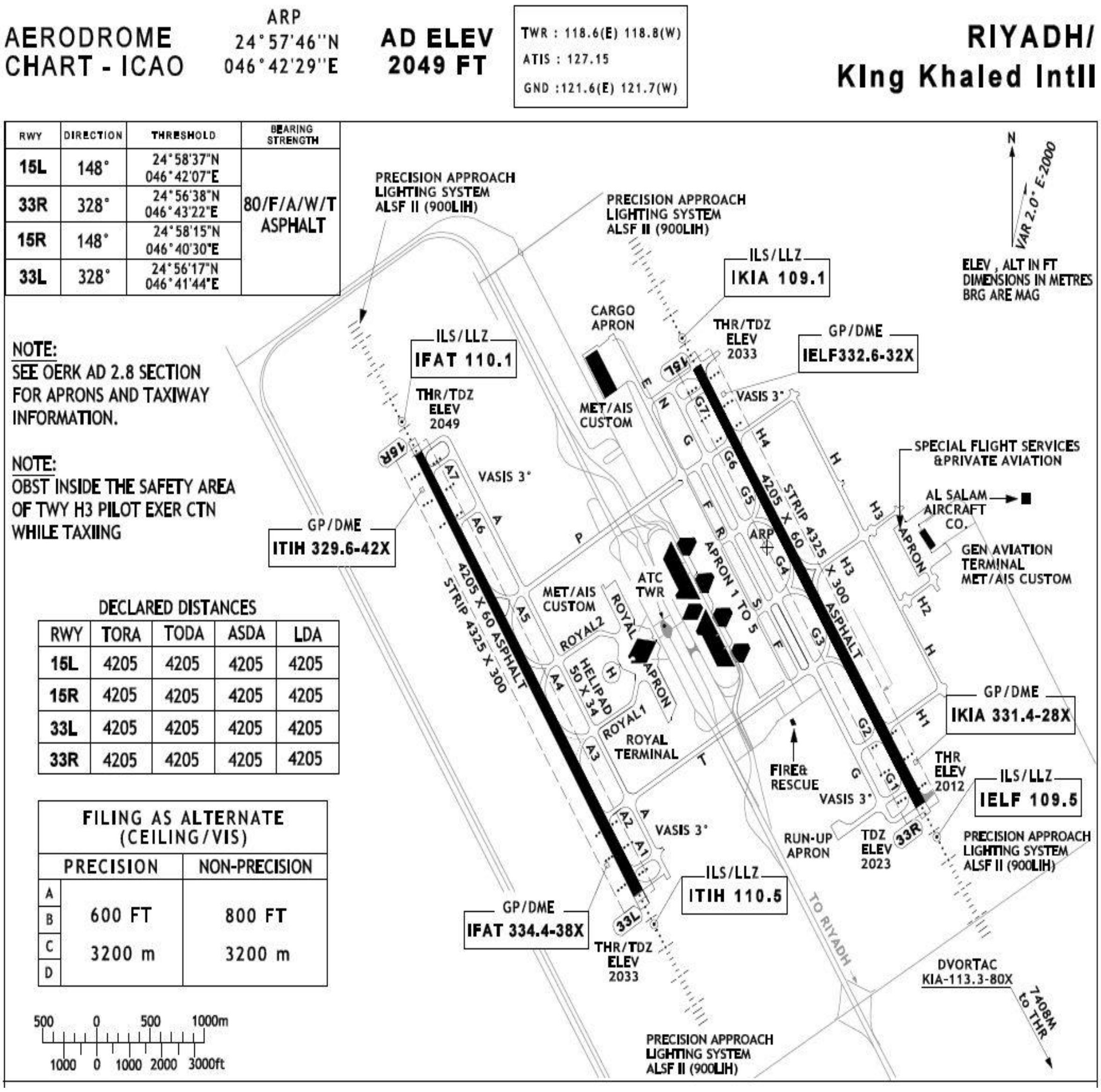

Figure 1: Riyadh Airport Chart

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1.10.2 Airport Status and ATC Actions

In the minutes that followed the accident, the ATC Ground/Tower Controllers closed runway 33L and stopped all movements of aircraft on the airport to facilitate the movement of the emergency vehicles. Since runway 33 Right (33R) was already closed prior to the accident, the airport was closed to all traffic while an inspection of runway 33R took place for its re-opening. Two aircraft had reached the threshold of runway 33L, while other aircraft were taxiing. The aircraft approaching the Riyadh airport were put into holding patterns.

Runway 33R was cleared for operations at 11h54. The aircraft on ground were then re-directed to the threshold of runway 33R. The 2 aircraft at the threshold of runway 33L were cleared to enter runway 33L and exit at taxiway Alpha 3 (A3) (Figures 1 and 25). Those 2 aircraft taxied over the landing evidence left on the runway by the MD-11F, but there was no debris from the MD-11F in the area between the runway threshold and taxiway A3.

1.10.3 Security Cameras

Security cameras were installed at many points around the KKIA-Riyadh airport. Some of those cameras captured the final approach and a portion of the landing of [redacted] and, portions of the FRS response. The video recordings from those cameras complemented the data retrieved from the aircraft flight recorders, the witnesses and the flight crew statements.

The time on the security camera system was 8 minutes behind the actual time/ATC time.

1.10.4 Airport Operations

The voice communication recordings of the KKIA-Riyadh Airport Operations were not available. The recording equipment either did not record or its listening functions were unserviceable. The precise nature of the problem was not determined. This situation had been present for a long time, including during previous events.

1.10.5 Airport Vehicles

Contrary to the KKIA-Riyadh Airport Procedures, some vehicles used within the airport perimeter were not equipped with rotary beacons. Those vehicles moved freely and were not escorted by vehicles with rotary beacons.

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1.10.6 Airport Security

The purpose of the Airport Security is to ensure that only authorized personnel and equipment can access the accident site area. The accident site includes all debris, traces of the aircraft path and the main wreckage area. At the initial stage, only the FRS personnel and equipment have access to the accident site/main wreckage area to save lives and property. Nobody else should have access to this area, until it is secured by the FRS.

The cordoned-off area must be large enough to allow free movement of FRS vehicles and keep all other personnel, including the security personnel, away from a possible fire/explosion.

During the initial stage of the fire fighting operations, the security guards were located within 50 meters (m) of the burning aircraft and were not controlling access to the main wreckage site. People other than FRS personnel were allowed to approach the burning aircraft within the security perimeter, including persons from the media. This aircraft still had 12,000kg of fuel in the wings. Had the fire reached this fuel, an explosion would likely have occurred and all the people located within 200m of the burning aircraft would have been seriously injured or killed.

Also, as the fire fighting operation continued during the day until 04h30 the next morning, people other than FRS personnel were present around the burning aircraft.

1.11 Flight Recorders

1.11.1 General

The Cockpit Voice Recorder (CVR) and the Digital Flight Data Recorder (DFDR) were located just aft of the lower center cargo door at Fuselage Station (FS 1801). Since this cargo door could not be opened to access the recorders and a lot of debris from the fire fell in this area, the firefighters used high powered metal cutting saws to cut through both the lower center cargo door and the fuselage aft of this cargo door (Figure 2). Both flight recorders were recovered.

The flight recorders had been exposed to and were heavily damaged by the fire (Figures 3 and 5). Both flight recorders were hand carried by the Accredited Representative of the BFU on 30 July 2010. The flight recorders were taken to the BFU facilities at Braunschweig, Germany for downloading of the data. The downloading took place from 31 July to 04 August 2010.

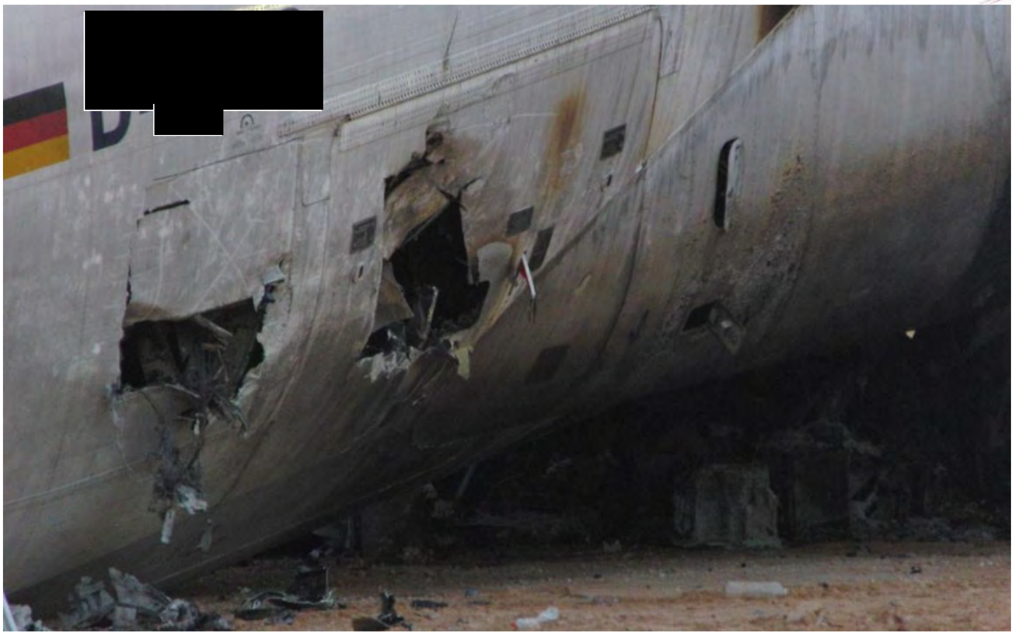

Figure 2: Access to the Flight Recorders

1.11.2 Digital Flight Data Recorder (DFDR)

The Digital Flight Data Recorder (DFDR) installed on D-A[redacted] was manufactured by Honeywell; Part Number 980-6022-001. The identification plate was unreadable due to the fire damage. The operator provided the following Serial Number: 6628

The recorder chassis and the Underwater Locator Beacon (ULB) had been destroyed by the fire. The Crash Survival Memory Unit (CSMU) showed minor mechanical damage with strong influence of fire on the painting and on the surface (Figure 3).

Figure 3: DFDR Unit

The memory board showed no damage and its temperature indicator was of a grey color indicating some heat exposure, but not critical (Figure 4).

The memory type was composed of solid state memory chips; the record configuration was 64 words per second and 12 bits per word; the duration was of 53 hours and 10 minutes of data and the useful flight data consisted of 9 flights including the accident flight, which had a duration of 18350 seconds (sec). The parameter list used was the McDonnell Douglas Corporation MD-11 flight recorder parameter data report number K1521, revision K dated 02 October 1995. There were 241 valid parameters and the recording quality was good with a low error rate. The download procedure was in accordance with the Honeywell recommended Accident Data Recovery (Doc HI 022-0010 REV B).

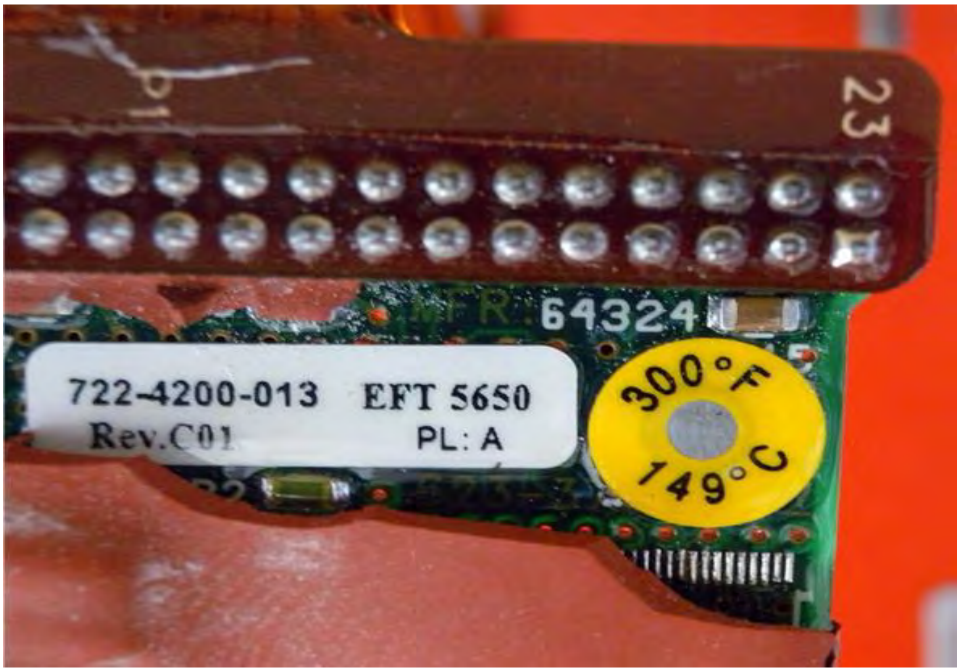

Figure 4: DFDR Memory Board

The data gathered from the DFDR complemented the data obtained from the flight crew, the eye witnesses and the video recordings from the airport security cameras. A flight animation was also created by the NTSB based on the DFDR data.

1.11.3 Cockpit Voice Recorder (CVR)

The Cockpit Voice Recorder (CVR) installed in D-A[redacted] was manufactured by Honeywell; Part Number 980-4700-003. The identification plate was unreadable due to the fire damage. The operator provided the following Serial Number: 2366

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The recorder chassis and the ULB had been destroyed by fire. The CSMU showed minor mechanical damage, strong influence of fire on the painting and on the surface and, attached molten material of unknown origin (Figure 5).

Figure 5: CVR Unit

The memory board showed no damage and its temperature indicator was of a grey color indicating some heat exposure, but not critical (Figure 6).

The memory type was composed of solid state memory chips; the recording durations were as follows: 30 minutes (min) for Channel 1/Spare, Channel 2/CM1 and Channel 3/CM2 and, 120 min for Channel 4/Area microphone and Channel 5/ Combined CM1+CM2+spare. The recording quality was good. The download procedure was in accordance with Honeywell recommended Accident Data Recovery (Doc HI 022-0010 REV B).

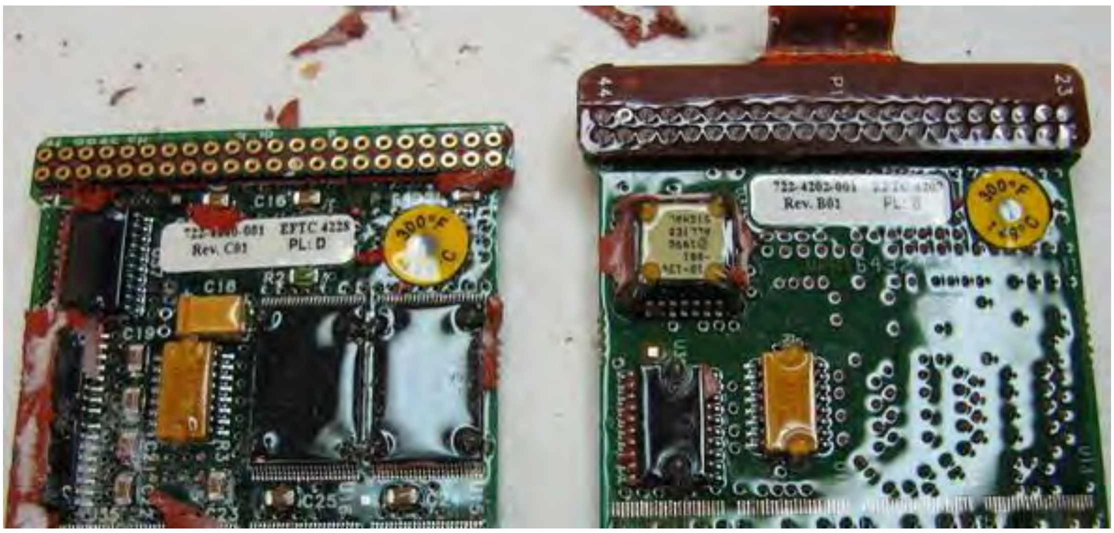

Figure 6: CVR Memory Board

1.12 Wreckage and Impact Information

1.12.1 Impact Information

The aircraft landed on Runway 33L at the 945 foot runway mark (green circle). The aircraft bounced following the first touchdown, touched down a second time and bounced a second time. A third and final touchdown at the 3200 foot runway mark (red circle) resulted in the aft section of the fuselage to rupture just aft of the wing. The aircraft continued down the runway with the tail dragging until it departed the left side of the runway at the 7400 foot runway mark, where the nose gear collapsed. After departing the runway, the aircraft traveled through a gravel area before it came to rest at the 8800 foot runway mark on a heading of 310°, 300 ft left of runway 33L centerline, across from taxiway exit A5 (Figures 7 and 8 and, Figure 3 of Appendix C). A fire started after the rupture of the aft fuselage.

Figure 7: General View of Wreckage Trail

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Figure 8: Marks and Debris

The runway and the wreckage trail were observed many times and, the marks and debris were documented and plotted. Significant items along the runway and wreckage path are as follows:

- Six parallel stripes of rubber residue were found 945 ft from the runway threshold indicating that the aircraft touched down with the two main landing gears and the centre landing gear. (Figure 7 - green circle and Figure 9 – green arrows);
- Tail impact at 3200 ft from the threshold. This impact consist of a deep gouge and additional scratches (Figures 7 and 10 – red circle). Beyond this point the number of parts and pieces increased;
- Starting at a point 3,500 ft from the threshold and slightly left of the runway centreline, two parallel stripes of rubber residue were found. The lateral distance of the stripes indicated that the traces came from the centre landing gear. (Figure 11 - blue arrow);
- Trace of the aircraft (off the runway). This trace leads directly to the main wreckage (Figure 12); and
- Main wreckage located 8800 ft from the threshold and 300 ft to the left of the runway centreline (Figure 12).

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Figure 9: First Touchdown

Figure 10: Tail Impact following Rupture of Fuseläge

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Figure 11: Centre Gear

Figure 12: Main Wreckage

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1.12.2 Wreckage Information

1.12.2.1 Fuselage

The aircraft fuselage was ruptured into two (2) major sections. The rupture was located at Fuselage Station (FS) 1441 just aft of the wing. The forward half section was supported by the main landing gear, which remained in the down position. The nose gear had collapsed aft and had punctured the forward lower cargo compartment, causing some crush damage to the lower fuselage and allowing the nose to rest on the ground. The nose gear was missing both tires, the right wheel and half of the left wheel. The slide had been activated at the L1 door. The slide was deflated and was resting on the ground detached from the aircraft (Figure 14).

There was fuselage buckling at FS 595 on the right side of the fuselage from the windows down. This buckling was severe and included skin tears and deformation. Less severe skin buckling was noted at various locations on the lower half of the fuselage from FS 595 forward to approximately FS 410 (Figure 13).

Figure 13: Buckling of Right Forward Fuselage

The left side of the fuselage showed skin buckling from FS 595 forward to FS410 (Figure 14).

Figure 14 : Buckling of Left Forward Fuselage and Deflated Slide

The top of the fuselage was burned through starting at FS 789 aft to the no.2 engine mount at FS 1986 (Figure 15). The fire consumed much of the cargo in the main deck compartment with the least amount of fire damage located at the forward end near the cockpit. The cockpit exhibited light soot deposits and the forward lower cargo compartment was undamaged by fire; the only damage to this compartment was from the nose gear which punctured through the floor. The aft lower cargo compartment was not accessed as the main deck cargo floor had collapsed into this area and it was filled with burned debris.

Figure 15: Fire Damage – Main Cargo Compartment

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The left wing root area displayed significant fire damage. The structure and skin on the lower half of the fuselage in the main gear area was largely consumed by the fire (Figures 15, 23 and 24).

1.12.2.2 Main landing gear

The left main landing gear remained intact (Figure 16). The wing rear spar, upper fixed brace, upper side brace, lower side brace, lock links, strut (PN NRG6719-501, S/N BFGS 01027) and truck had no visible damage that would suggest gear failure or strut over-compression. The chrome extension on the strut measured 4.75 inches (in.) and the paint below the chrome did not demonstrate signatures of strut over-travel. All four (4) tires were inflated.

The center main landing gear remained relatively intact; however, the aircraft structure surrounding the gear attach points was largely consumed by fire. The gear sat slightly forward and to the right of the normal down and locked position. The strut (no visible data plate), gear braces and truck had no visible damage that would suggest gear failure or strut over-compression. The chrome extension on the strut measured 9.5 in. and the paint below the chrome did not demonstrate signatures of strut over-travel. The two (2) tires were inflated.

Figure 16: Main Landing Gear

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The right main landing gear remained intact. The wing rear spar, upper fixed brace, upper side brace, lower side brace, lock links, strut (PN NRG6719-501, S/N BFGS 01028) and truck had no visible damage that would suggest gear failure or strut over-compression. A piece of speed tape type material was located just above the junction of the upper side brace and upper fixed brace. This speed tape was partially peeled back. There was also evidence of an imprint on the bottom side of a wheel well upper panel that appeared to have been made by a hinge located on the upper fixed brace. The chrome extension on the strut measured 4.13 in. and the paint below the chrome did not demonstrate signatures of strut over-travel. All four (4) tires were inflated.

All main landing gear tires were Bridgestone H54-21.0-24 tires with Thompson retreads. The tires showed various amounts of scuffs and damage.

1.12.2.3 Wings

The left wing was mostly undamaged with the exception of fire damage on the aft inboard area. The inboard flap was damaged by fire and remained attached to the wing at the outboard end only. The flap actuator was covered in soot with some shiny chrome extension on the piston near the actuator housing. The inboard aileron was in a downward position and also demonstrated some discoloration due to fire. The outboard flap was extended and appeared to be at or near the end of the flap tracks. The outboard aileron was slightly up and the leading edge slats were fully extended (Figures 17 and 18).

Figure 17: Extended Leading Edge Slats

The right wing was mostly undamaged with the exception of the aft inboard area, which damage was not as extensive as to the left wing. The inboard flap remained attached to the wing at the outboard end only. The inboard side of the flap was tucked under the trailing edge of the wing. There was some damage to the trailing edge of the wing in this area that appeared consistent with the flap being torn out from the wing. The inboard aileron was in a downward position. The outboard flap was extended and appeared to be at or near the end of the flap track. The outboard aileron was slightly up and the leading edge slats were fully extended (Figures 17 and 18).

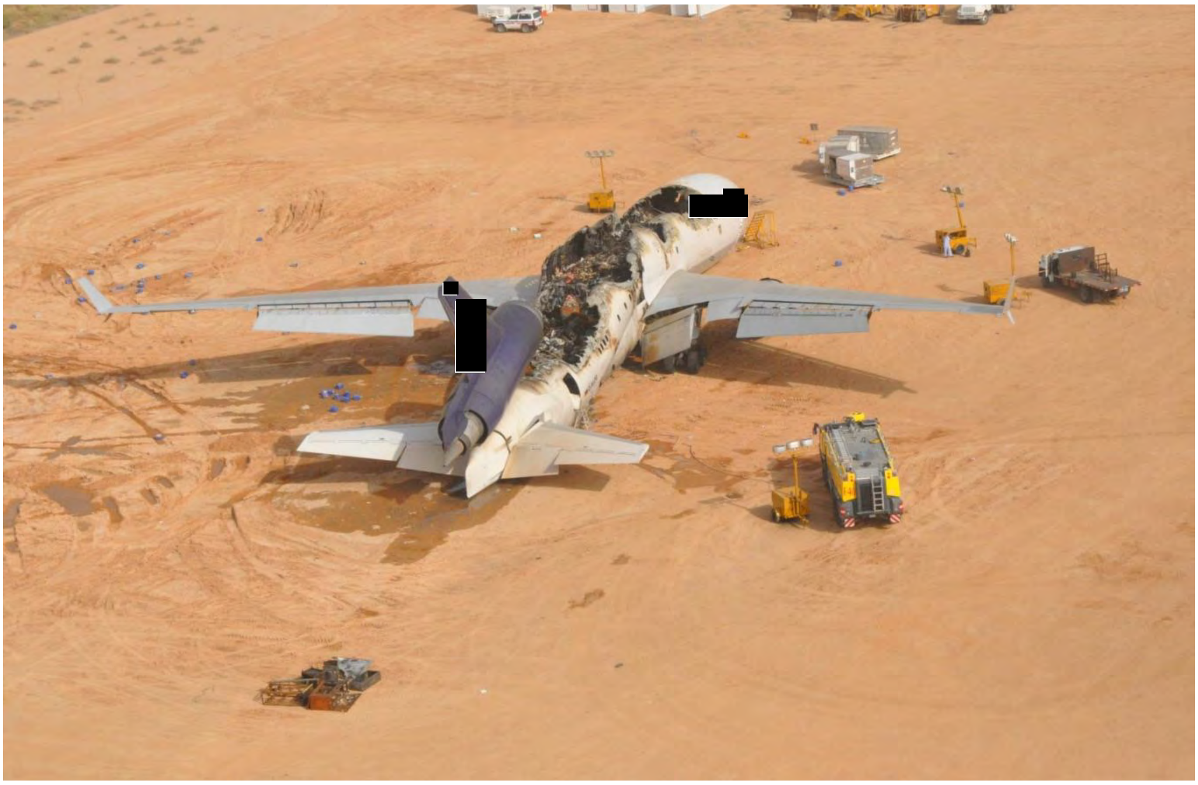

Figure 18: Position of Flight Control Surfaces

1.12.2.4 Aft fuselage and stabilizers

The forward section of the aft fuselage was supported off the ground by its remaining connection with the forward half of the fuselage at FS 1441. The tail section was resting on the ground and was deformed and buckled in various places on the lower half of the fuselage. Fire damage was extensive on the left side, with the most severe damage near the wing root and becoming less apparent near the tail. The tail cone was translated aft by 6 in. at FS 2162. This gap went around the entire circumference of the fuselage and engine pylon fairing, as well as the left side of the no. 2 engine nacelle (Figures 21a and 21b).

The left horizontal stabilizer leading edge measured 18.25 in. below the reference line on the fuselage. There was a dark rubber like mark that extended

84 in. along the inboard leading edge (Figure 21a). The outboard elevator was in a slightly down/faired position, while the inboard elevator was in a mostly down position.

The right horizontal stabilizer leading edge measured 12 in. below the reference line on the fuselage. The outboard elevator was in a slightly down/faired position, while the inboard elevator was in a mostly down position. The vertical stabilizer and the rudder appeared in good condition. The top half of the rudder was deflected more to the right than the lower half (Figures 17 and 18).

1.12.2.5 Cockpit area

The cockpit area had light deposits of soot but did not exhibit heat damage. The position of the cockpit controls, switches and circuit breakers were documented. It was not possible to check for control continuity due to the damaged condition of the fuselage.

The following control positions were noted:

- Fire Handle Engine no. 1: NORM
- Fire Handle Engine no. 2: Gen. Field Disconnect
- Fire Handle Engine no. 3: NORM
- Flap Limit: Auto
- Elev. Feel: Auto
- Long. Trim: Handle was 3.75 in from aft end of slot and 3.25 in from forward end of slot
- Engine Throttle Quadrant: All levers full aft and reverser handles deployed
- Flaps: 35 degrees (°)
- Fuel Shutoff Valves: OFF
- Spoilers: Retracted and disarmed
- Auto Brake: MIN
- Aileron trim: 0°
- Rudder Trim: 0°
- Landing gear: Down

The list of the circuit breakers which were found opened is at Appendix A.

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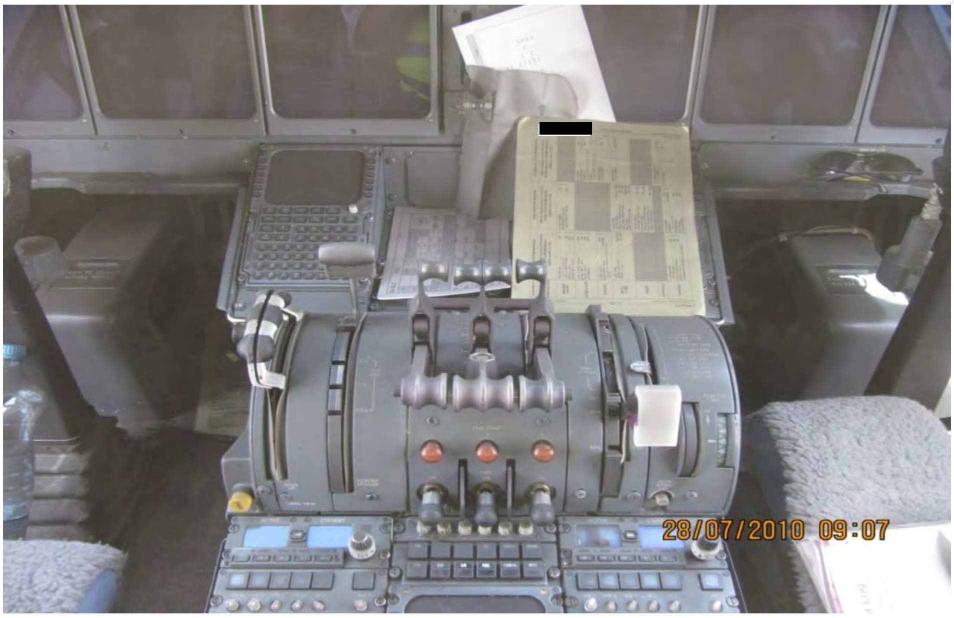

Figure 19: Centre Pedestal

1.12.2.6 Power Plants

Left/No. 1 Engine

The engine remained attached to the wing with the front of the engine resting on the ground. The first row of fan blades had some damage on the leading edge of the blades. The first row of stator vanes was intact. Both reverser sleeves were extended and all blocker doors were closed. The reverser exhaust cascades appeared relatively clean, containing only a small amount of dirt and debris. A visual inspection revealed that the last row of turbine blades was in good condition and all blades were accounted for (Figure 20).

Figure 20: Left/No. 1 Engine

Centre/No. 2 Engine

The engine was attached to the tail/vertical stabilizer. The inlet engine housing was damaged by the fire in the fuselage. There was a gap on the engine pylon fairing at FS 2162 and the left side of the engine nacelle was split at this location. The right side reverser sleeves were retracted and the blocker doors appeared open. The left side reverser sleeves were extended and the blocker doors were closed. There was a small amount of unidentified debris in the reverser exhaust. A visual inspection revealed that the last row of turbine blades appeared in good condition (Figures 21a and 21b).

Figure 21a: Centre/No. 2 Engine

Figure 21b: Centre/No. 2 Engine

Right/No. 3 Engine

The engine remained attached to the wing with the front of the engine resting on the ground. The engine intake cowling was damaged and mostly separated from the engine. There was a seventeen (17) in. long black mark on the intake leading edge. There was one (1) ft by 1 ft piece of nose gear tire lodged in the outboard housing where the intake cowling had separated from the engine. The first row of the fan blades and stator vanes had sustained substantial damage. Both reverser sleeves were extended and all blocker doors were closed. The reverser exhaust cascade contained debris consisting of dirt, engine nacelle and tire material. A visual inspection revealed that the last row of blade vanes appeared in good condition (Figure 22).

Figure 22: Right/No. 3 Engine

1.13 Medical and Pathological Information

There was no evidence that incapacitation or physiological factors affected the flight crew performance.

The FRS paramedics took both flight crews to the Riyadh Airport Hospital.
The Captain sustained minor cuts to the head. The Captain was released from the hospital two (2) days after the accident. The FO was transferred from the Riyadh Airport Hospital to the Riyadh Military Hospital on the same day. The

FO had sustained spinal injuries that required major surgery and hospitalization. The Surgeon recommended that the FO be given sufficient time to recover from his injuries prior to being interviewed. The following week, the FO was flown to Germany to complete his rehabilitation. The first interview with the FO was conducted on 31 August 2010. The FO's spinal injuries occurred during the landing phase.

1.14 Fire

1.14.1 General

1.14.1.1 Damage to aircraft

The video recordings from the airport security cameras showed there was no smoke or fire until shortly after the aft fuselage ruptured at FS1441during the landing. As the aircraft was rolling down the runway, smoke was coming out from the top of the fuselage at the fuselage break. When the aircraft came to a stop, the smoke increased, but the fire was not apparent. According to the Fire & Rescue Services (FRS) firefighters, the fire was initially located in the wheel well of the center main landing gear. The fire later became apparent from the crown of the fuselage during the firefighting efforts. The fire was extinguished at 04h30 the next morning. In the days that followed, the fire re-ignited on two (2) occasions.

The aircraft exhibited wide-spread fire damage particularly in the crown area of the fuselage aft of the wing. The fire damage to the crown began just aft of the forward cargo door and extended to the engine mount of the no. 2 engine (Figures 15, 17 and 18).

The upper crown of this area of the fuselage was completely destroyed with all of the fuselage skin missing and most of the stringers either missing or melted. The fire damage extended down the sides of the fuselage to approximately half the height of the main cargo deck. In several places, the damage extended to the aft lower cargo deck. The upper edges of the remaining fuselage were melted with bubbled or missing exterior paint. The area of heaviest damage was located on the left side of the aircraft just aft of the wing where the aircraft fuselage ruptured. This area exhibited heavy melting of the fuselage as well as large areas of missing material which extended underneath the aircraft. In this area, the main cargo floor was damaged and as a result, several pieces of fire damaged cargo fell out of the aircraft after it came to rest. The center landing gear well shroud was melted, as was its upper structure (Figures 23 and 24).

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Figure 23: Area of Heaviest Fire Damage (Left Side)

Figure 24: Main Landing Gear Area (Left Side)

The left wing was heavily damaged at the root. The wing skin was mostly melted away in this area, leaving only the stringers.

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The forward portion of the no. 2 engine cowling had heavy soot with the left side of the cowling exhibiting heavier damage than the right side. The forward edge of the engine mount showed evidence of melting (Figure 21a).

1.14.1.2 Fuel system

A fuel line servicing the no. 2 engine/Auxiliary Power Unit (APU) and, a tail tank fuel transfer line were both located in the cheek area on the left side of the aircraft. Both lines were 2.0 inches in diameter. The no. 2 engine/APU fuel line had an operating pressure of 28 to 38 pounds per square inch (psi). The tail tank fuel transfer line was not pressurized during the landing and only residual fuel would have been present in the line. The no. 2 engine/APU fuel line would have had fuel flow until the booster pumps were shutoff. These 2 lines were separated at the couplings in the area just aft of the left wing in the fuselage break area. This was the area with the heaviest fire damage.

1.14.1.3 Cargo

The cargo was packaged in a combination of pallets and rigid cargo containers. The cargo on the main deck had varying degrees of fire damage. The cargo located in the forward area was relatively undamaged with the exception of water damage as a result of the firefighting efforts. Some of this cargo had been removed from the aircraft by the firefighters to facilitate their access to the fire. The rest of the cargo exhibited some degree of fire damage with the heaviest damaged cargo located in the area near and aft of the fuselage break. The cargo in the forward lower compartment showed no fire or water damage.

There were forty-four (44) shipments of dangerous goods on the aircraft. Most of these shipments were located in the forward lower cargo compartment which were not damaged by the fire. The dangerous good shipments in this area were later removed and released to the Saudi Customs of the Riyadh airport. Twelve (12) shipments were located in the aft portion of the aircraft. These shipments contained corrosive materials, toxic materials, magnetized materials and flammable liquids. These shipments were either heavily damaged or destroyed by the fire.

1.14.1.4 Ignition source

The break in the no. 2 engine/APU fuel line and the tail tank fuel transfer line resulted in fuel being sprayed into the left wheel well area, which likely fed the initial fire. Due to the heavy damage from the fire, the ignition source could not be determined.

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1.14.1.5 Fire protection system

The cargo compartments were classified as Class E for the main deck and Class C for the lower deck. Fire detectors were installed in the overheads of both cargo decks. The lower deck compartments were equipped with a total flood Halon 1301 system. Each compartment was protected by the same Halon bottles. None of the systems had been activated.

1.14.2 Fire Fighting

1.14.2.1 Initial Response

When the FO declared a Mayday while the aircraft was sliding off the runway, the ATC Ground Controller declared Alert 3 by contacting the Fire & Rescue Services (FRS) and passing the basic information. At the same time, FRS personnel situated in the FRS Station 2 located near the intersection of taxiways Alfa (A) and Papa (P) saw the MD-11F sliding and exiting the runway with black smoke emanating from the top of the fuselage (Figure 25).

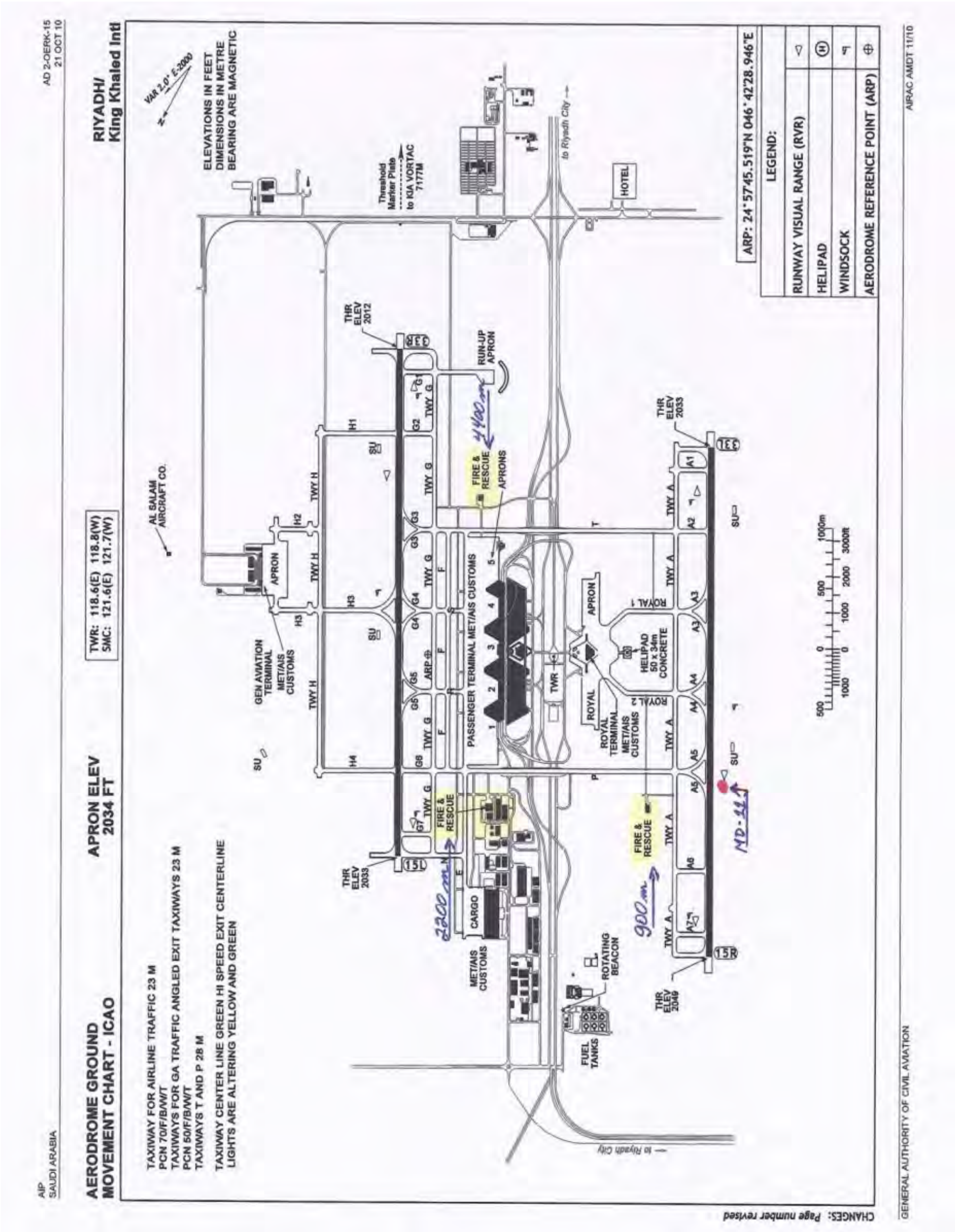
When the Alert 3 came in from the ATC Ground Controller, the FRS personnel in FRS Station 2 were already taking action. There were two (2) other FRS Stations located within the Riyadh airport perimeter (Figure 25). There were also two (2) other FRS stations (Stations 4 and 5) located outside the airport perimeter, but within a close distance.

An airport security camera located on the left side of runway 33L and close to the final resting position of the MD-11F captured the aircraft as it traveled in the gravel area. As the aircraft slid from right to left, black smoke was emanating from the break in the fuselage and a cloud of dust was also present. This cloud of dust disappeared quickly and the FRS Station 2 came into view. A first FRS vehicle was seen leaving the FRS Station 55 seconds (sec.) after the MD-11F crossed in front of the camera. A second FRS vehicle left the same FRS Station 20 sec. later. Those 2 FRS vehicles crossed runway 33L respectively 1 min. and 40 sec. and 1 min. and 55 sec. after leaving FRS Station 2.

In the minutes that followed, the ATC Ground/Tower Controllers stopped all movements of aircraft on the airport to facilitate the movement of the emergency vehicles.

After a general alert was given, FRS vehicles from the other FRS Stations were dispatched to the MD-11F. Units from the Main Station and Station 1 responded as did units from Stations 4 and 5 located outside the airport perimeter. Off duty personnel were recalled and the Civil Defense was called

[redacted]



[redacted] Riyadh.

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Figure 26: Fire Fighting Operations

1.14.2.2 Fire Fighting & Rescue Operations

When the first FRS responders got to the aircraft, both pilots had already evacuated the aircraft via the slide situated at the L1 door. The Captain had some minor cuts, while the FO was complaining of back pain. The FRS paramedics took both flight crews to the Riyadh Airport Hospital. During the whole fire-fighting operation, two (2) FRS personnel suffered from heat exhaustion.

In the hours following the accident, the FRS contained the fire and continued its operations to eliminate the source of the fire. During this period, smoke was present and some FRS personnel directly involved in the operation were not wearing the breathing apparatus which is part of their Personal Protective Equipment (PPE). Also, some FRS personnel in uniform climbed on top of the burned cargo to watch the fire fighting operations; those personnel were not wearing any PPE.

The fire fighting operation continued until 04h30 the next day, 28 July 2010 (Figure 26). The accident site was released to the Investigator-In-Charge (IIC) at 10h30 on 28 July 2010.

During the entire site investigation, at least one (1) manned FRS unit was continuously present at the accident site.

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In the days that followed, the fire re-ignited on two (2) occasions, but was put out quickly. The recurrent ignition source was attributed to smoldering cargo situated under the debris within the aft cargo compartment. The smoldering cargo was activated by the strong daily winds. To eliminate those recurring fires, heavy lift equipment was used to remove the burned debris and the floor of the upper cargo compartment which had collapsed on top of the ignition source of the recurring fires. This area was then completely cooled down.

1.14.2.3 FRS Recordings

The FRS recordings were available and were of good quality. The time on the FRS recordings was out of synchronization and ahead of the ATC time by 1 hour and 24 minutes.

1.15 Survival Aspects

After the aircraft stopped and the fuel was turned OFF, the Captain kicked the partially jammed cockpit door. At that time, the FO mentioned he could not move his legs. The Captain opened the L1 door and deployed the slide. As he returned to the cockpit, the FO was standing and they both jumped down the slide. The flight crew had no difficulty evacuating the aircraft.

1.16 Tests and Research

1.16.1 Rupture of the Aft Fuselage

The aircraft, including the fuselage, was designed and certificated to withstand loads up to the ultimate design loads, which include a safety margin of 50 percent (%) above the design limit loads. The limit loads result from a number of operational conditions prescribed by the certification criteria. For the MD-11F, the Center of Gravity (C of G) limit vertical load *(nlf)* factor is 2.3g. This vertical load factor is directly related to the loads and stresses carried by the aircraft structure.

Considering the factor of safety that is prescribed in 14 CFR 25.3030, the calculated ultimate vertical load factor is: 2.3g x 1.5 = 3.5g.

On the first and second touchdowns, the aircraft sustained two (2) vertical load peaks within 2.5 seconds, of 2.1g and 3.0g respectively. On the third touchdown, the aircraft sustained a vertical load of 4.4g; this was significantly higher than the design ultimate vertical load factor of 3.5g. This is when the aft fuselage ruptured from overload. The three (3) vertical loads imposed onto the aircraft took place within a period of seven (7) seconds.

1.16.2 Aircraft Performance Study

1.16.2.1 General

An Aircraft Performance Study was conducted by the NTSB. The study is partially presented at Appendix C. The objectives of this study were to determine and analyze the motion of the aircraft (i.e., the aircraft position and orientation as a function of time) and the physical forces that produced that motion, including the aircraft response to control inputs and other factors that could have affected its trajectory. The following data was used for this study:

- Video recording of the landing captured by the airport security camera;
- Ground scars and markings;
- DFDR and QAR data; and
- The ILS system geometry.

The video recording of the landing captured by the airport security camera (Appendix C- Figure 1) showed that after the first touchdown of the main gear, the aircraft bounced back into the air and then touched down a second time with both the main gear and nose gear in a nearly flat pitch attitude. The aircraft bounced again with the nose rising rapidly. This second bounce was much higher than the first. The aircraft again pitched over and returned to the runway. Following this third touchdown, the aircraft exited the field of view of the security camera.

The runway scars and the condition of the wreckage indicated that after the last touchdown, the rear section of the fuselage behind the wing ruptured and collapsed, folding towards the runway about a "hinge" on the bottom of the fuselage in the area of the rupture.

Figure 1 in Appendix C contains a series of still frames from the video recording of the airport security camera from a point on final approach at t = -1.5 seconds (sec.) before the first touchdown to the exit of the aircraft from the camera field of view following the last touchdown at about t = 7.9 sec. after the first touchdown. The first touchdown occurs at t = 0.0 sec.

Several ground scars and markings provided evidence of the aircraft trajectory following the first touchdown. (Figures 7 to 12 and Appendix C - Figure 3)

This study covered many aspects of the flight. The pitch control and responses during the bounces were of particular interest. Figures 18a and 18b in Appendix C present the longitudinal flight control parameters. Control column position and, left and right column forces are shown in the top plots in the figures; the resulting elevator positions are shown in the middle plots, together with the recorded horizontal stabilizer position and, the aircraft pitch rate and pitch angle are shown in the bottom plots.

1.16.2.2 Factors affecting vertical load factor (*nlf*) at touchdown

The first touchdown (main gear) at a *nlf* of 2.1g and -13 ft/sec resulted from a flare initiated between 1.7 and 2.0 sec./23 to 31 ft above the runway before touchdown. This is indicated by the start of the up movement of the elevators and the increase in pitch angle (Appendix C – Figure 18b). The first touchdown resulted in a bounce. The severity of the subsequent hard touchdowns was not a necessary consequence of the first touchdown, but primarily the result of the pitch angle behavior during the bounces.

The severity of the second touchdown (main gear and nose gear) at a *nlf* of 3g and -11 ft/sec. resulted from an unloading of the aircraft from 1g to about 0.4g during the first bounce, associated with a 6° reduction in angle of attack (from 8° to 2°) and a reduction of 6° of pitch angle (from 6.5° to 0.5°) with the initial deployment of the spoilers, which are commanded to 30° following main-wheel spin up. A spoiler deflection of 30° is equivalent to a decrease in angle of attack of about 3°, which resulted into a total reduction in lift during the first bounce equivalent to a decrease in angle of attack of about 9°. This second touchdown resulted in a bounce to a height of about 12 ft.

The third touchdown resulted in the rupture of the fuselage, following a recorded *nlf* of 4.4g imposed on the airframe. This load factor resulted from an excessive rate of descent during the third touchdown of about -17ft/sec., which was the result of the unloading (reduction of lift) of the aircraft during the second bounce. The unloading is apparent in the decay of *nlf* from about 1.3g to 0.4 g just before the last touchdown. The reduction in lift resulted from the combination of a decrease in the angle of attack with the full extension of the spoilers. The angle of attack decreased by 7.5° (from 12.5° to 5°) and, the spoilers reached their full extension of 60° following the compression of the nose gear strut during the second touchdown. The reduction in angle of attack was the result of the reduction in pitch angle from 14° to about 2°. The reduction of lift due to the full spoiler extension was equivalent to a decrease in angle of attack of about 4.5°. The total reduction of lift during the second bounce was equivalent to a decrease in angle of attack of about 12°.

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1.16.2.3 Factors affecting pitch angle (θ) behavior

The pitch angle (θ) of an aircraft is driven primarily by its inherent longitudinal stability characteristics and the motion of the longitudinal control surfaces (horizontal stabilizer and elevators).

Figure 18b at Appendix C indicates that between *t* = -0.5 and 1.5 sec., the elevators moved from 10° UP (where they had been previously commanded by the First Officer's (FO) aft column input during the flare) to 14° DOWN. As a result, the pitch rate and the θ responded promptly to these nose-down control inputs.

During this time, the Longitudinal Stability Augmentation System (LSAS) elevator command progressed from 2.4° DOWN elevator command at *t* = -0.5 sec. to a 2° UP elevator command at *t* = 1.5 sec.. This movement was primarily the result of the Pitch Rate Damping (PRD) function of the LSAS responding to the decrease in pitch rate from 2.7 deg/sec. at *t* = -0.4 sec. to -4.7 deg/sec. at *t* = 1.5 sec.. These movements indicate that the LSAS was commanding elevator movements to attenuate the unloading of the aircraft during the first bounce.

Figure 18b at Appendix C also indicates that the control column moved from 2.5° aft to about 9° forward during the first bounce. The low sample rate of the column data (approximately 1 Hz) prevents a precise definition of the column motion; however, the data point at 9° forward is 73% of the 12.3° forward limit. This indicates a substantial push on the control column, which in turn was the primary drive of the elevator position and the decrease in θ during the first bounce.

Figure 18b at Appendix C further indicates that the large nose-down column input during the first bounce was made primarily by the Captain, who was the Pilot Monitoring (PM). Prior to the first touchdown, the force on the Captain's column was approximately zero (0), while the FO's column forces were non-zero, thus confirming the FO was the Pilot Flying (PF).

The FO pulled about 24 pounds (lb) on the control column during the flare and, following the first touchdown he relaxed the pull and actually pushed modestly with about 1 to 3.5 lb. The first data point for the Captain's control column following the first touchdown indicates a push of almost 18 lb, which was maintained for at least 1 sec.. The magnitude of the forward control column motion following the first touchdown was primarily the result of the forces exerted on the Captain's control column.

Figure 18b at Appendix C indicates that just prior to the second touchdown (main gear and nose gear), which occurred at t = 2.3sec., both the Captain and the FO pulled on the control column. This input moved the control column about 10° aft and resulted in the elevators moving to a maximum recorded position of 28° UP. This large nose-up elevator input, together with large ground reaction forces on the nose gear during the flat-pitch touchdown resulted in a large nose-up pitch rate of over 8 deg/sec. during the second bounce.

Early in the second bounce, the control column moved forward and as during the first bounce, the Captain's control column recorded a push of 16 to 18 lb for at least 2 sec., which were much larger than the FO's, which relaxed to about +/- 2 lb. At t = 6.7 sec., the FO's control column recorded a push of 9.4 lb. As a result of these forces, the control column reached its forward limit during the second bounce and the elevators responded accordingly by reaching their nose-down limit and remaining there for about 2 sec.

During the second bounce, the LSAS commanded its authority limit of 5° nose-down elevator, while the pitch rate was positive (nose up). At about t = 5 sec. and in response to the nose-down elevator commands, the pitch rate reversed from positive to negative reaching a minimum value of about -7.6 deg/sec. at about t = 6.3 sec. Following this reversal, the LSAS commands became increasingly nose-up and saturated at the 5° nose-up authority limit.

The third touchdown occurred at about t = 7.5 sec. Prior to the third touchdown, the Captain and the F/O both pulled back again on the control column, though at slightly different times. The Captain initiated his pull between t = 5.7 and 6.7 sec., and the F/O initiated his pull between t = 6.7 and 7.7 sec. At t = 6.7 sec., the Captain pulled with 18 lb force on the control column, while the F/O pushed with 9.4 lb force on the control column. Consistent with the stronger force exerted by the Captain, the control column moved aft from -9.3° to +12.6°. The elevators responded to these inputs from 24.9° DOWN to 29.5° UP. At t = 6.3 sec., the pitch rate started to increase, but the aircraft was still pitching down during the third touchdown, which occurred one (1) second later.

The top plot of Figure 21 at Appendix C shows the height above the runway of the landing gear, the aircraft Center of Gravity (C of G) and the cockpit as a function of time. The bottom plot in Figure 21 shows the rate of change of these parameters. From t = 1.0 to 1.7 sec. during the first bounce, the cockpit descends, while the C of G and gear climb. This effect results from the decreasing pith angle (θ) and the consequent vertical translation of the cockpit as the aircraft rotates about the C of G, which is about 89 ft behind the cockpit.

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1.17 Organizational and Management Information

1.17.1 Company information

[redacted] is a leading international air cargo carrier. It is a separate airline wholly owned by [redacted] based in Frankfurt, Germany. It carries the [redacted], but it has its own ICAO code: [redacted]. [redacted] flies to thirty-nine (39) destinations in Africa, America, Asia and Europe. At the time of this accident, the company's fleet consisted of eighteen (18) MD-11F aircraft.

1.17.2 Management officials

At the time of this accident, there were four (4) primary management officials with direct responsibility for flight operations:

- Vice President Transport Management/Flight Operations;
- Head of Flight Operations;
- Head of Training; and
- Quality Manager and Safety Pilot.

For the MD-11F fleet, there were four (4) managers reporting to the Head of Flight Operations:

- Fleet Captain;
- Fleet Captain Operations & Deputy Head of Fleet;
- Fleet Captain Technical; and
- Chief Flight Instructor.

1.17.3 Operating procedures

The rules and procedures approved by the company for operating the MD-11F were incorporated into a series of manuals. The Operations Manual – General (OM-A) described the rules and procedures which pertained to all aircraft. The Operations Manual – Airplane (OM-B) described procedures specific to the MD-11F. The OM-C contained the syllabus for the MD-11 training and the OM-D was the training manual.

Section 8.3.14.3 (Sink Rate) of the OM-A stated in part:

" *Normal sink rate at touchdown averages to 120 ft/min. An aeroplane is certified with a sink rate of 360 ft/min at the structural limited TOW and with*

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600 ft/min at the maximum landing weight. Structural problems will not arise, if sink rates at touchdown do not exceed 360 ft/min."

Page 6 of Section 2.1.60 (Normal Procedures – Landing) of the OM-B stated:

" It is recommended to use manual throttles during manual flight (ATS should be switched off latest at 200 ft AGL).

Below 10 ft with the airplane fully flared (sink rate approx. 2-4 ft/sec), the basic technique is to maintain attitude by applying the required control wheel Pressures. A more advanced technique is to actually begin lowering the nose (approx. 1 degree) prior to main gear touchdown.

Ground spoiler deployment causes a nose up pitching moment. This effect is most noticeable at aft centers of gravity. It is important to resist any pitch up tendency with forward pressure on the control column and smoothly lower the nose wheel to the runway. The LSAS, on airplane with FCC 908 will assist the pilot in the nose lowering task."

The company provided pilots with separate training guidance information on a variety of subjects under the title TRIM. This document provided guidelines on the expected pitch, power and flare height for different gross weights and circumstances affecting the landing and, it described common errors during landing.

This document stated the following about flare height:

" – Flare height: depends on weight because of the mass inertia. At high weights (>200t) the flare has to be initiated at ~ 40 ft. At light weights (~130t) a flare just prior 20ft is sufficient. Furthermore, pressure altitude influences the flare height – due to the higher TAS & the corresponding higher vertical speed the flare has to be initiated a bit earlier than usual (NBO: 6000 ft-> TAS increase by 18kt (3kt/1000ft) – flare 10 ft earlier."

1.18 Additional Information

1.18.1 [redacted] flight crew training

The MD-11F aircraft was referred to by the instructing staff of [redacted] as a very special aircraft, which required to have a speedy scan and quick reaction time.

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The MD-11F was the only wide body aircraft operated by [redacted] which required that landing training be done routinely in the aircraft, as opposed to being conducted solely in a simulator. This landing training was required, because of the wide range of landing conditions encountered during freighter operations, such as landings at very light to very heavy weighs and operations at the edge of the performance envelope. Also, the simulator could not duplicate the dynamics of hot runways, thermals and choppy conditions.

1.18.2 [redacted] bounced landing recovery training

[redacted] required all its flight crews to complete bounced landing recovery training in the simulator, even though the ability of the simulator to capture the true sensation of a complicated event such as a bounced landing was limited.

During the simulator training, both pilots knew that a bounced landing would occur. The instructor would be doing the flying and would intentionally land hard without a flare. This produced a bounce after which the other pilot was expected to take control, maintain 7 1/2° of pitch and apply go-around thrust. This procedure had been in use at [redacted] for the last ten (10) years.

1.18.3 Boeing FCOM - Bounced Landing Recovery Technique

The Boeing MD11 Flight Crew Operating Manual (FCOM) dated 15 August 2009 stated under the heading " Bounced Landing Recovery":

"*If the aircraft should bounce, hold or re-establish a normal landing attitude and add thrust as necessary to control the rate of descent. Avoid rapid pitch rates in establishing a normal landing attitude.*

CAUTION: Tail strikes or nose wheel structural damage can occur if large forward or aft control column movements are made prior to touchdown.

When a bounced landing occurs, consider initiating a go-around by use of normal go-around procedures. Do not retract the landing gear until a positive rate of climb is established, because a second touchdown may occur during the go-around."

1.18.4 MD-11 Bounced and Severe Hard Landing Events

During the period from 02 August 1992 to 27 July 2010, there were twenty-nine (29) "MD-11Bounced and Severe Hard Landings resulting in Substantial Aircraft Damage" (Appendix B).

1.18.5 Recognition of a bounced landing

From interviews conducted with [redacted] personnel and other general information gathered throughout this investigation, it appears that the recognition of a bounce landing with the MD-11F is difficult. The difficulty is that flight crews do not know that the aircraft is airborne after the landing. This difficulty comes mainly from the fact that the flight crews do not feel/sense a bounce and there is no visual or oral indication of a bounce.

The instructing staff at [redacted] believed that the only way to identify a bounced landing in the aircraft was through the radar altimeter. Since flight crews rarely, if not ever, watch the instruments following the flare and during the landing, this identification method was not practical and at best, difficult to apply.

Another air carrier operating a fleet of MD-11F has installed Head-Up Displays (HUDs) on all its MD-11F aircraft and is in the process of installing this equipment on other types of aircraft composing its fleet. The HUDs are supplemented by an Enhanced Flight Visibility System (EFVS). EFVS is a HUD system modified to display Forward-Looking Infrared (FLIR) imagery. This air carrier installed HUD/EFVS to be used primarily as a safety tool and to derive a potential benefit from lower landing minima for approaches. This HUD also provide an indication of a bounced landing.

The HUD provides the flight crew with instantaneous aircraft flight path information and the landing cue provides precise dynamic flare guidance based on the aircraft performance. When the flight crew follows the landing cue, the result will be a perfect landing with a safe touchdown within the touchdown zone on any runway. The HUD also provides an indication to the flight crew that the aircraft has bounced, but there is a slight delay before this indication appears. The addition of the EFVS enhances visibility at night and in other low visibility conditions; the EFVS function does not provide information regarding bounced landings.

In addition, this air carrier focuses on the training of its flight crews to land properly and, to recognize a landing that is not going as planned and to execute a missed approach when required.

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2.0 ANALYSIS

2.1 General

The analysis will discuss the aircraft, the meteorological conditions, the flight crew members, the MD-11F simulator, bounced landings, the KKIA Airport Operations, the response of the FRS, the site security, the synchronization of time at KKIA and the security cameras.

2.2 The aircraft

2.2.1 General

The aircraft was properly certificated and had been maintained in accordance with approved procedures.

2.2.2 Response of control surfaces

The aircraft and in particular the elevators responded to the flight crew inputs on the control column. The LSAS commands remained within its authority limits and as such, there was no evidence to indicate that the LSAS may have contributed to this accident.

2.2.3 Aircraft damage

The aft fuselage ruptured at FS 1441 as a result of a high vertical load factor of 4.4g during the third touchdown. The consequent vertical loads overstressed the fuselage and caused it to rupture. This rupture of the fuselage damaged and severed controls, wiring and fuel lines to the no. 2 engine/APU and the tail tank fuel transfer line. As a result, fuel sprayed into the left hand wheel well area and ignited. Due to the extensive damage created by the fire, the exact source of the ignition could not be determined.

There was no evidence of airframe failure or system malfunction prior to the accident. All damage to the aircraft was attributable to the hard landings and the fire that ensued.

2.2.4 Position of the flight recorders

The Cockpit Voice Recorder (CVR) and the Digital Flight Data Recorder (DFDR) were located just aft of the lower center cargo door at Fuselage Station 1801. This location was exposed to the fire and consequently, the recorders were damaged. The recording medium survived the fire and the data was recovered. Normally, flight recorders are located within the empennage where damage due to fire/impact is minimized.

2.3 The meteorological conditions

The meteorological conditions at the Riyadh airport were not a concern, nor did they contribute to this accident.

2.4 The flight crew members

2.4.1 General

The flight crew members were certified and qualified on this type of aircraft. They both had received the appropriate and approved training.

2.4.2 The flight crew actions

The first touchdown (main gear) at a *nlf* of 2.1g and a sink rate of -13 ft/sec resulted from a late flare initiated by the FO between 1.7 and 2.0 sec/23 to 31 ft above the runway before touchdown. This is indicated by the start of the upward movement of the elevators and the increase in pitch angle (Appendix C – Figure 18b). While the first touchdown resulted in a bounce, the landing was recoverable. The severity of the subsequent touchdowns was not a consequence of the first touchdown, but primarily a result of the pitch angle during the bounces, which resulted from the actions of both flight crews on the control column.

The reasons for the flight crew inputs on the control column cannot be analyzed in the same manner as the response of the aircraft to those inputs. The responses of the flight control surfaces and the aircraft control inputs are governed by quantifiable laws of physics, while the actions of human beings are not. In general, flight crews make control inputs based on their perception of the aircraft motion as compared to their desired aircraft trajectory. The parameters that may affect the flight crews' perceptions of the aircraft motion include: the height of the cockpit above the runway, the rate of change of the height of the cockpit, the pitch angle and the pitch rate, the load factors in the cockpit, the control force feedback and the cockpit and engine sounds.

The pitch angle (θ) behavior of the aircraft during the bounces was consistent with the movements of the elevators, and these in turn, were consistent with the control columns inputs made by the flight crews. In particular, the large nose-down control column input by the Captain during the first bounce, which

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unloaded the aircraft and led to the second hard, flat touchdown and, subsequent large second bounce.

The reason for this large nose-down input by the Captain is unclear. One possibility is that the Captain did not realize the aircraft had bounced and was attempting to de-rotate the aircraft while assuming the main gear were still on the ground. Of note, from $t = 1.0$ to 1.7 sec. during the first bounce, the cockpit descended, while the C of G and gear climbed. This effect resulted from the decreasing pith angle (θ) and the consequent vertical translation of the cockpit as the aircraft rotated about the C of G, which was about 89 ft behind the cockpit. The decreasing cockpit height during this time may have made it more difficult for the pilots to determine that the aircraft had bounced and that the main gear were no longer on the runway.

The large control column inputs made by both flight crews during the second bounce are somewhat easier to understand, as the large pitch rates near the ground may have surprised or alarmed them, thereby confusing the flight crews and leading to large responses on the control column.

Handover of controls was never mentioned by either flight crew. The Captain should have stated "I have control" from the moment where he input the forward movement during the first bounce. This resulted in both flight crews acting on the controls, and not always in unison, thus aggravating a serious situation.

2.5 MD-11 Simulator

The MD-11 simulator did not provide a true and accurate simulation of the bounce conditions found with the aircraft. The artificial actions to initiate a bounce in the simulator reduced the value of the training.

2.6 Bounced landings

On long aircraft, where the cockpit is located some distance from the main gears and the center of gravity of the aircraft, flight crews may have difficulty in perceiving that the aircraft has bounced. On such aircraft, certain combinations of pitch rate and climb rate may result in the cockpit height above the runway during a bounce to remain constant or even decrease, while the height of the main gears increases. This situation is potentially confusing to flight crews attempting to discern whether the main gears are on the ground and, may result in attempting to de-rotate the aircraft while the main gears are in the air; thus leading to a potential severe second touchdown on the nose gear followed by a serious rebound.

Flight information provided by a Head-Up Display (HUD) may assist flight crews in determining whether the main gears are in fact on the ground, or whether the aircraft has bounced. An air carrier using HUDs in its MD-11F aircraft indicated that with proper training and the proper use of HUDs, bounced landings are either avoided or recognized by flight crews in order to take appropriate action.

2.7 KKIA-Riyadh Airport Vehicles

Some vehicles used within the airport perimeter were not equipped with rotary beacons. Those vehicles moved freely and were not escorted by vehicles with rotary beacons. This was contrary to the KKIA-Riyadh Airport Procedures and created a safety risk to all users within the maneuvering areas.

2.8 KKIA-Riyadh Airport Operations

The voice communication recordings of the KKIA-Riyadh Airport Operations were not available. The recorder equipment either did not record or its listening functions were unserviceable. This situation had been present for a long time, including during previous events. It was therefore not possible to fully analyze the response of the Airport Operations during this event.

2.9 FRS Response

Two (2) FRS units reached the aircraft within three (3) minutes after the aircraft came to a complete stop. Following the general alert, FRS vehicles from the other FRS Stations were dispatched to the MD-11F. Off duty personnel was recalled and the Civil Defense was called in reinforcement. When the first respondents got to the aircraft, both pilots had already evacuated the aircraft. The FRS paramedics took both flight crews to the Riyadh Airport Hospital.

The initial FRS response was rapid and efficient. The fire fighting operation continued until 04h30 the next day, 28 July 2010. In the hours following the accident, the FRS contained the fire and continued its operations to eliminate the source of the fire. During this period, smoke was present and the FRS personnel directly involved in the operation were not wearing the breathing apparatus which is part of their Personal Protective Equipment (PPE). Also, some FRS personnel in uniform climbed on top of the burned cargo to watch the operations; those personnel were not wearing any PPE. Breathing smoke which comes from burning dangerous cargo and not wearing any PPE in close proximity to an aircraft fire could lead to disastrous results.

In the days that followed, the fire re-ignited on two (2) occasions due to smoldering debris activated by the daily strong winds, but was put out quickly. The continuous presence of an FRS manned unit at the accident site ensured the safety of all concerned.

2.10 Airport Security

When an aircraft accident occurs within the airport boundaries, it is the role of the Airport Security to ensure that only authorized personnel and equipment can access the accident site area.

In the immediate period following an aircraft accident, the security personnel complement, support and facilitate the fire and rescue operation, protects all other personnel from possible injuries and preserve all evidence related to the accident for the investigation. This is a critical role and the access to an accident site must be strictly enforced.

For this purpose, the cordoned-off area must be large enough to allow free movement of FRS vehicles and keep all other personnel, including the security personnel, away from a possible fire/explosion.

In this case, during the initial stage of the fire fighting operations, the security guards were located too close to the burning aircraft and were not controlling access to the main wreckage site. Persons other than FRS personnel were allowed to approach the burning aircraft, including persons from the media. Had the fire reached the 12,000kg of fuel in the wings, all the people located within 200 meters (m) of the aircraft would have been seriously injured or killed.

2.11 Synchronization of time

The time associated with ATC tapes is accurate and available in UTC. During investigations, all the communications and other available information are analyzed. In order to properly assess responses by different groups, the time associated with recordings must be accurate.

Since no recordings from the KKIA Airport Operations were available, the time issue was not evaluated. But significantly, the FRS recordings were 1 hour and 24 minutes out of synchronization with the real time associated with the ATC recordings. Also, the time associated with the airport security cameras was out of synchronization by 8 minutes.

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Accurate time, whether in UTC or local time is paramount, as it reflects the actions and responses of intervening parties and paints an accurate picture of the sequence of events.

2.12 Security cameras

The purpose of security cameras is not to resolve aircraft accidents. But in this case, the video recordings of the security cameras played an important role by supplying and confirming information gathered from other sources.

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3.0 FINDINGS

3.1 Cause Related Findings.

1. The flight crew did not recognize the increasing sink rate on short final.

2. The First officer delayed the flare prior to the initial touchdown, thus resulting in a bounce.

3. The flight crew did not recognize the bounce.

4. The Captain attempted to take control of the aircraft without alerting the First Officer resulting in both flight crews acting simultaneously on the control column.

5. During the first bounce, the Captain made an inappropriate, large nose-down column input that resulted in the second bounce and a hard landing in a flat pitch attitude.

6. The flight crew responded to the bounces by using exaggerated control inputs.

7. The company bounced-landing procedure was not applied by the flight crew.

3.2 Other Findings

1. The flight crew was properly licensed and was qualified on the type of aircraft.

2. The meteorological conditions did not contribute to the accident.

3. The aircraft was properly certificated and had been maintained in accordance with approved procedures.

4. The aircraft had no oral or visual indicator, such as a HUD, to inform the flight crew of a bounced landing.

5. The flight recorders were located just aft of the lower center cargo door.

6. The FRS response was rapid and efficient.

7. During the FRS operation, some FRS personnel were not wearing their PPE.

8. Time synchronization at the KKIA airport was deficient.

9. KKIA Airport Operations recordings were not available.

10. Some KKIA Airport vehicles did not have rotating beacons.

11. KKIA Airport Security did not maintain proper control of the accident site during the initial response to the accident.

12. KKIA Airport security cameras provided information that was useful to the investigation.

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4.0 SAFETY RECOMMENDATIONS

Recommendations 1 and 2 are Stand Alone Recommendations (SAR) that were issued by the NTSB to the FAA on 12 July 2011, under agreement with the SD of the GACA/S&ER.

1. The FAA should require Boeing to revise its MD-11 Flight Crew Operating Manual to reemphasize high sink rate awareness during landing, the importance of momentarily maintaining landing pitch attitude after touchdown and using proper pitch attitude and power to cushion excess sink rate in the flare, and to go around in the event of a bounced landing (A-11-68).

   Safety Action was taken by Boeing on 15 February 2011. The MD-11 Flight Crew Operating Manual was revised by Boeing in accordance with the stated recommendation A-11-68.

2. Once Boeing has completed the revision of its MD-11 Flight Crew Operating Manual as recommended in Safety Recommendation A-11-68, the FAA should require all MD-11operators to incorporate the Boeing-recommended bounce recognition and recovery procedure in their operating manuals and in recurrent simulator training (A-11-69).

3. [redacted] should consider installing Head-Up Displays (HUDs) on its MD-11F aircraft.

4. The GACA shall ensure that all Departments using recording devices at both International and Domestic airports throughout the KSA synchronize the time of the recording devices with the ATC time.

5. The GACA shall ensure that Airport Security Services properly cordon-off accident sites to avoid the possibility of serious/fatal injuries to bystanders and, allow only the authorized personnel and equipment to enter the cordoned-off area, as per the Airport Emergency Plan.

6. The GACA shall ensure that all personnel involved in fire fighting operations wear the appropriate Personal Protection Equipment (PPE) when required.

7. The GACA should consider installing cameras with recording capability at all its airports within the KSA to cover all movement areas for security purposes and to supplement information available for investigation of aviation occurrences.

8. The GACA shall ensure that the KKIA Airport Operations Department have a functioning recording device for all its communications.

9. The GACA shall ensure that all vehicles operating within the KKIA airport boundaries are equipped with rotating beacons.

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APPENDIX A

CIRCUIT BREAKERS

The following circuit breakers were found opened:

- HYD MOTOR PUMPS CONTROL 1-3
- HYD MOTOR PUMPS CONTROL 2-3
- PARKING BRAKE VALVE
- APU SYSTEM AND DOORS PWR
- FIREX CONTROL AGENT 1
- FIREX CONTROL AGENT 2&3
- HYD SYS 3 ELEV SHUTOFF
- ENG 2 AND APU FIRE AGENT DISCHARGE LT
- FUEL TANK FILL VALVE AND BAT BUS SENSING
- APU FIRE WARN LT
- APU FIRE WARN HORN
- FUEL FIRE S/O VLV PRIMARY ENG 1
- FUEL FIRE S/O VLV PRIMARY ENG 3
- CARGO SMOKE DET & LIGHTS
- CARGO OVERHEATH
- FLAP/AOA 1
- HYD QTY IND 3
- TAIL TANK LXFR
- AUX TANK RLWR
- LAV DRAIN MAST HEATH
- HYD PRESS IND 1
- CENTER CARGO HEATH/VENT
- NOSE LANDING TAXI LIGHT L
- NOSE LANDING TAXI LIGHT R
- MAIN W/W AND CENTER ACCESS COMPT LIGHT

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APPENDIX B

MD -11 Bounced and Severe Hard Landing Events

	NTSB Number	MM/DD/YR	City	State/Country	Event	Operator	Reg.	Have FDR Data	Variant
1	ATL92IA151	8/2/1992	Los Angeles	California	Tailstrike during landing	Delta Air Lines	N803DE	Yes	MD-11
2	LAX93IA198	4/30/1994	Los Angeles	California	Bounced hard landing	Delta Air Lines	N803DE	Yes -	MD-11
3	ANC95FA008	11/4/1994	Alaska	Anchorage	Tailstrike and hard landing	FedEx	N611FE	Yes - Tabular Data	MD-11F
4	CHI94MA290	9/24/1995	Chicago	Illinois	Bounced landing improper flare	Alitalia	IDUPO	Yes -	MD-11F
5	ANC96FA072	5/16/1996	Anchorage	Alaska	tail strike on go around attempt	Fedex	N614FE		MD-11F
6	LAX96FA206	12/16/1996	Los Angeles	California	Tailstrike w/ no spoiler use	Korean Airlines Co. LTD	HL737	Yes -	MD-11
7	DCA97MA053	6/21/1997	Honolulu	Hawiai	AP disconnect and tailstrike	Garuda Indonesian Airways PT	EICDK		MD-11
8	DCA97MA055	7/31/1997	Newark	New Jersey	Wing spar break and rollover	FedEx	N611FE	Yes - plots, CSV	MD-11F
9	DCA98WA005	10/24/1997	Montevideo	Uruguay	tailstrike on landing	World Airways, Inc.	N275WA		
10	DCA99WA036	12/25/1998	Shanghai	China	Tailstrike during landing	China Eastern Airlines	B2174		MD-11
11	AAIB	5/19/1999	Cambridge	England	Tailstrike during bounced landing	Delta Air Lines	N813DE	Yes - plots, CSV	MD-11
12	DCA99WA072	8/8/1999	Shanghai	China	Departed runway during landing	China Eastern Airlines			MD-11
13	DCA99RA073	8/22/1999	Hong Kong	China	Wing spar break and rollover	China Airlines	B-150		MD-11
14	DCA99WA085	9/18/1999	Shannon	Ireland		World Airways, Inc.	N272WA		MD-11
15	DCA02WA007	11/20/2001	Taipei	Taiwan	Hard landing w/ nose gear	EVA Air	B-16101		MD-11
16	DCA02WA022	2/3/2002	Dublin	Ireland	Departed runway during landing	Delta Air Lines	N803DE		MD-11
17	DCA04MA011	12/18/2003	Memphis	Tennessee	RH Main Gear Collapse	FedEx	N364FE	Yes - plots, CSV	MD-10
18	FTW04WA066	1/26/2004	Mexico City	Mexico	Tailstrike during landing	Varig Airlines	PP-VTF		MD-11
19	DCA04MA082	9/19/2004	Memphis	Tennessee	Tailstrike during go aournd	FedEx	N602FE	Yes - plots, CSV	MD-11F
20	NYC05FA094	6/7/2005	Louisville	Kentucky	Previous flight hard landing, with potential b	UPS	N250UP		MD-11F
21	DCA06FA058	7/28/2006	Memphis	Tennessee	LH Main Gear Collapse	FedEx	N391FE	Yes - plots, CSV	MD-10
22	DCA06WA072	9/14/2006	Subic Bay	Phillipines	tail strike on landing	FedEx	N623FE		MD-11F
23	DCA07WA009	11/7/2006	Paris	France	CLG failed on landing	FedEx	N584FE		MD-11F
24	DCA09RA041	3/23/2009	Narita	Japan	Left wing spar break and rollover	FedEx	N526FE	Yes	MD-11
25	DCA09FA048	5/6/2009	Baltimore	Maryland	hard landing, left nose tire fail	World Airways, Inc.	N139WA		MD-10-30
26	DCA09WA059	9/6/2009	Khartoum	Sudan	Hard Landing	Saudi Arabian Airlines	HZ-ANB	Yes - Tabular Data	MD-11
27	ENG10SA008	9/13/2009	Mexico City	Mexico	Hard Landing	[redacted]	[redacted]	Yes - binary	MD-11
28	DCA10WA004	10/20/2009	Montevideo	Uruguay	Hard Landing	Centurion Air Cargo Inc	N701GC	Yes - binary	MD-11
29	DCA10RA079	7/27/2010	Riyadh	Saudi Arabia	Hard Landing, hull loss	[redacted]	[redacted]	Yes	MD-11F

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APPENDIX C

AIRCRAFT PERFORMANCE STUDY
(REPORT RELATED FIGURES)

Figure 1 (page 1 of 3). Still frames from first security camera.

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Figure 1 (page 2 of 3). Still frames from first security camera.

Figure 1 (page 3 of 3). Still frames from first security camera.

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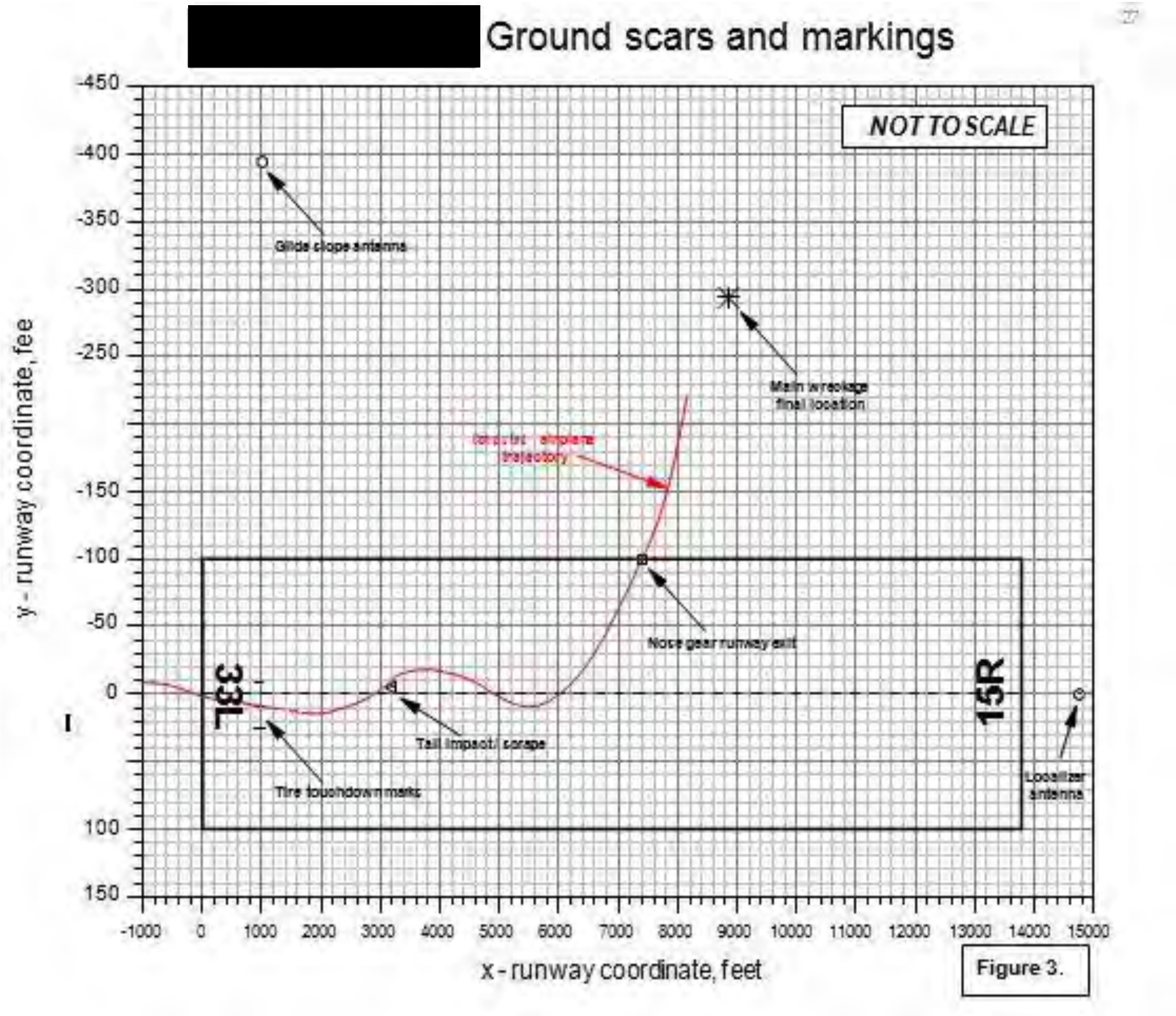
[redacted] Ground scars and markings
NOT TO SCALE
Glide slope antenna
Main wreckage final location
trajectory
Nose gear runway exit
33L
15R
Tail impact / scrape
Tire touchdown marks
Localizer antenna
y - runway coordinate, fee
-450
-400
-350
-300
-250
-150
-100
-50
0
100
150
-1000
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
13000
14000
15000
x - runway coordinate, feet
Figure 3.

[redacted] Longitudinal controls

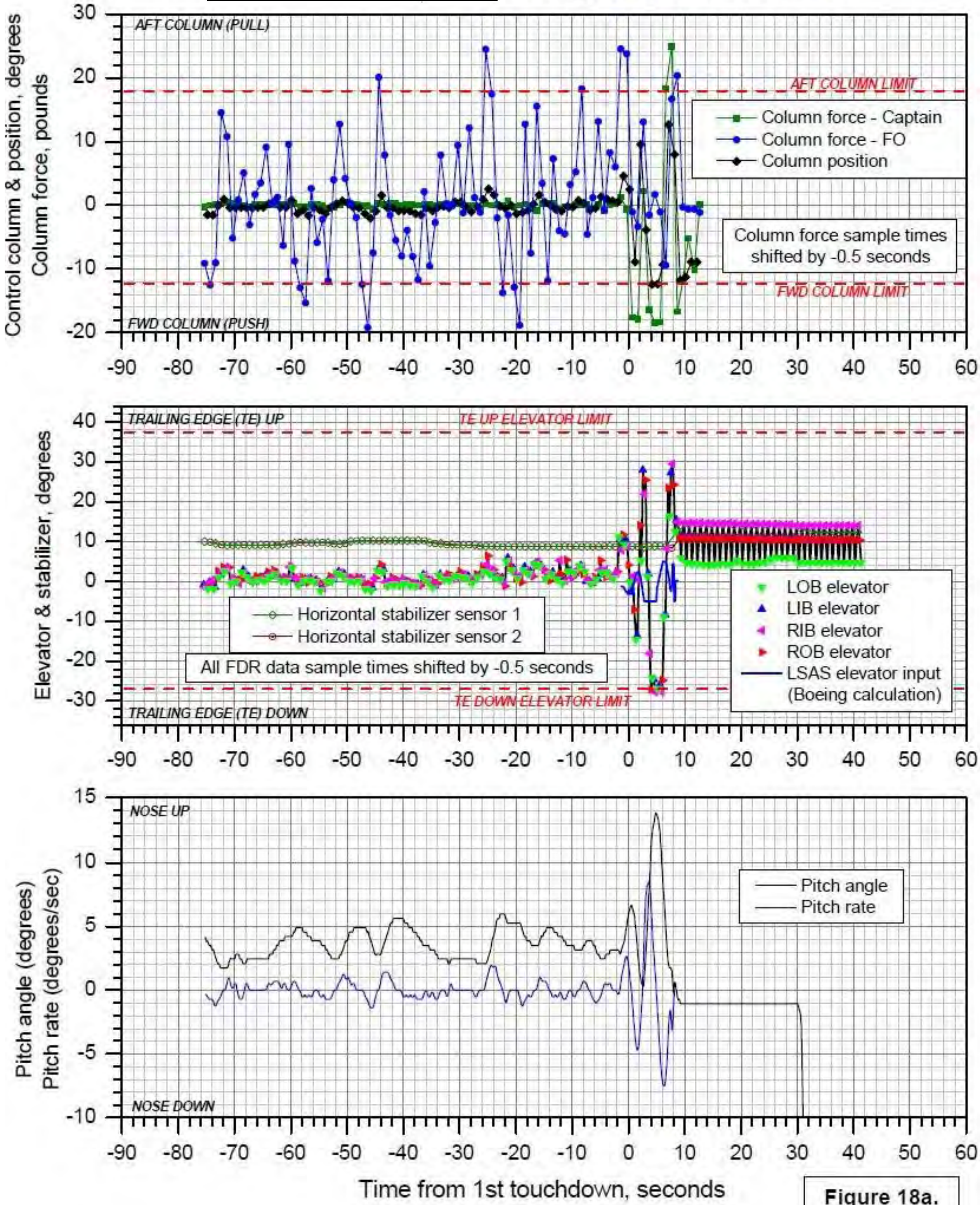

Figure 18a.

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[redacted] Longitudinal controls (detail)

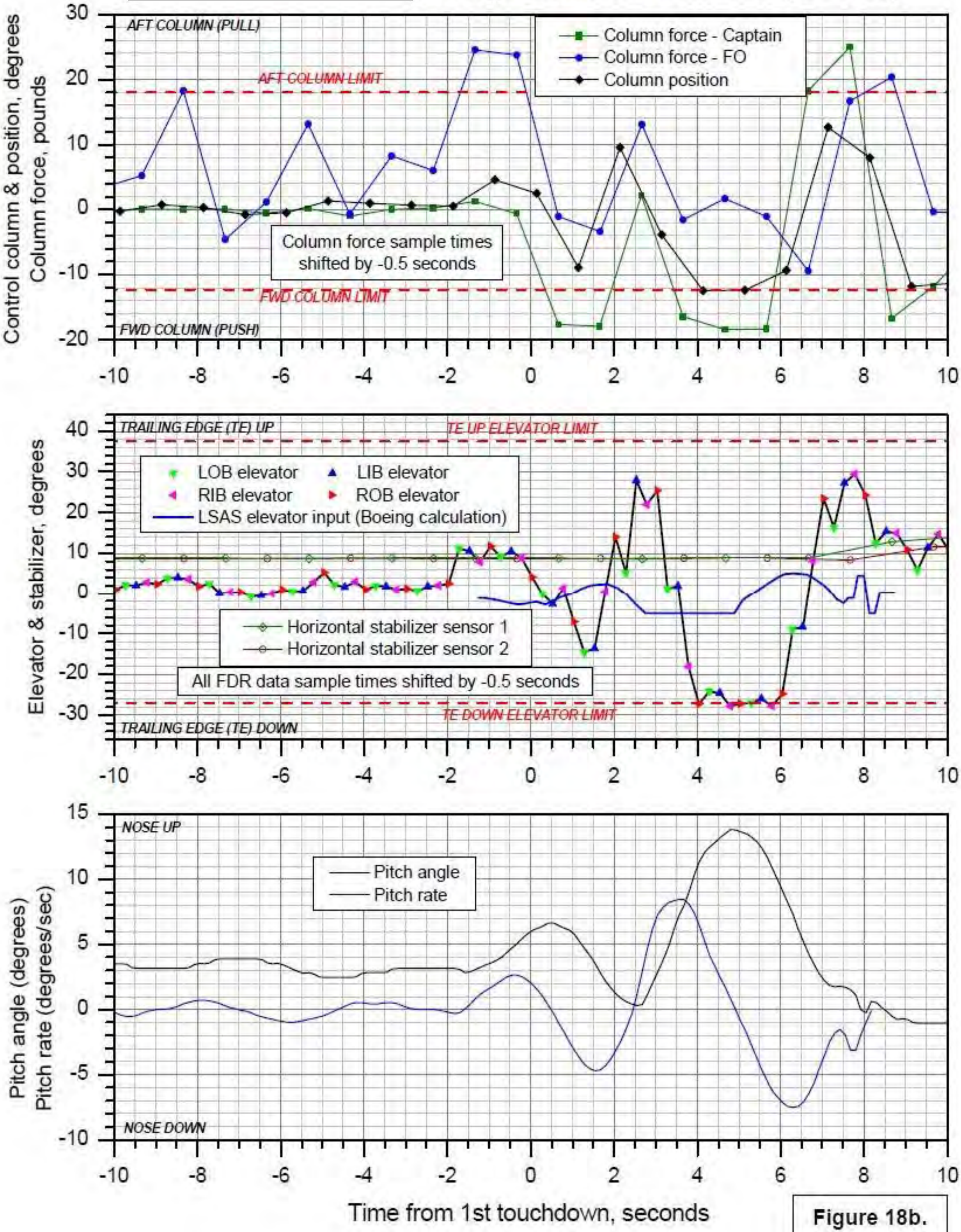

Figure 18b.

[redacted] Lateral controls

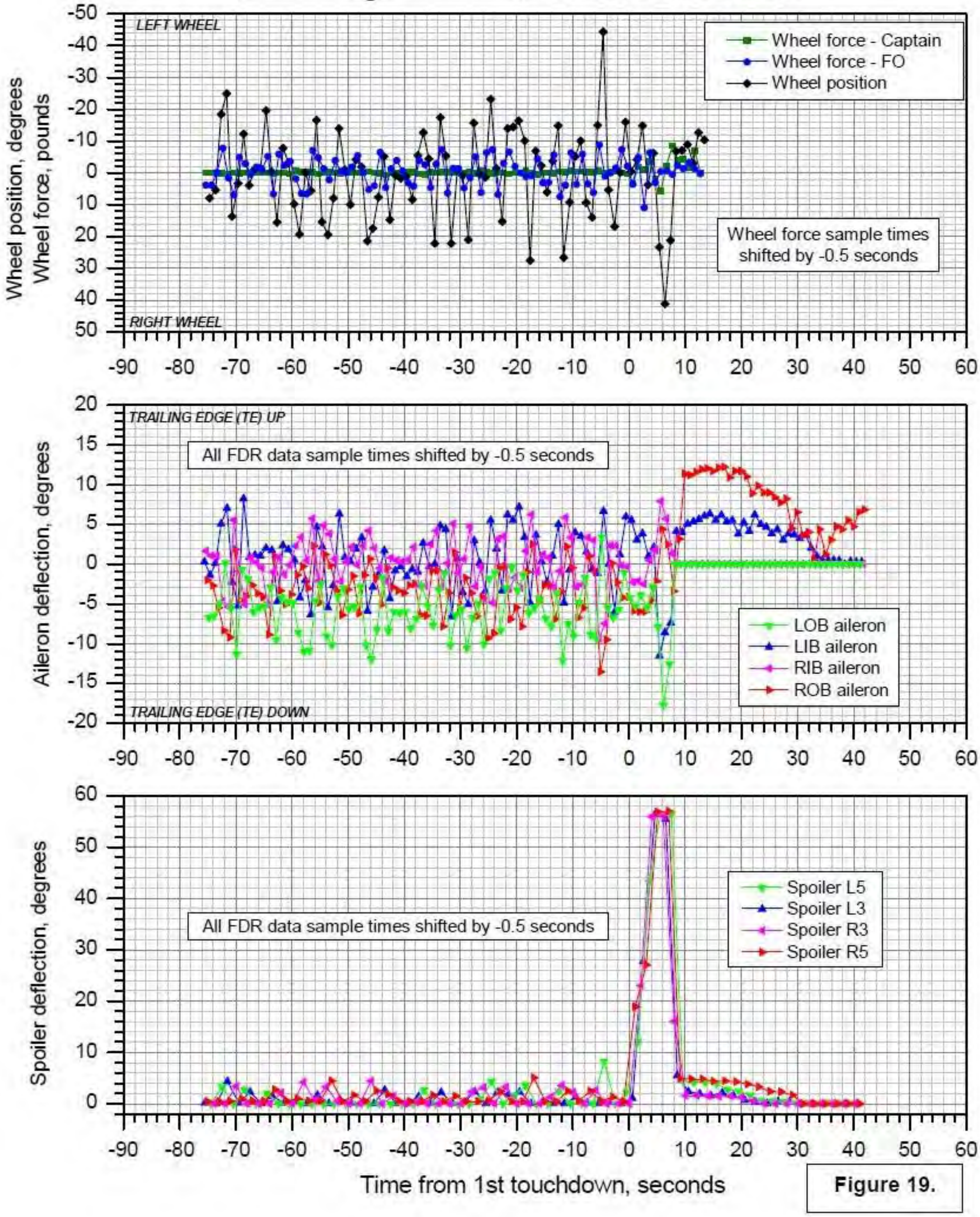

Figure 19.

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[redacted] Directional controls

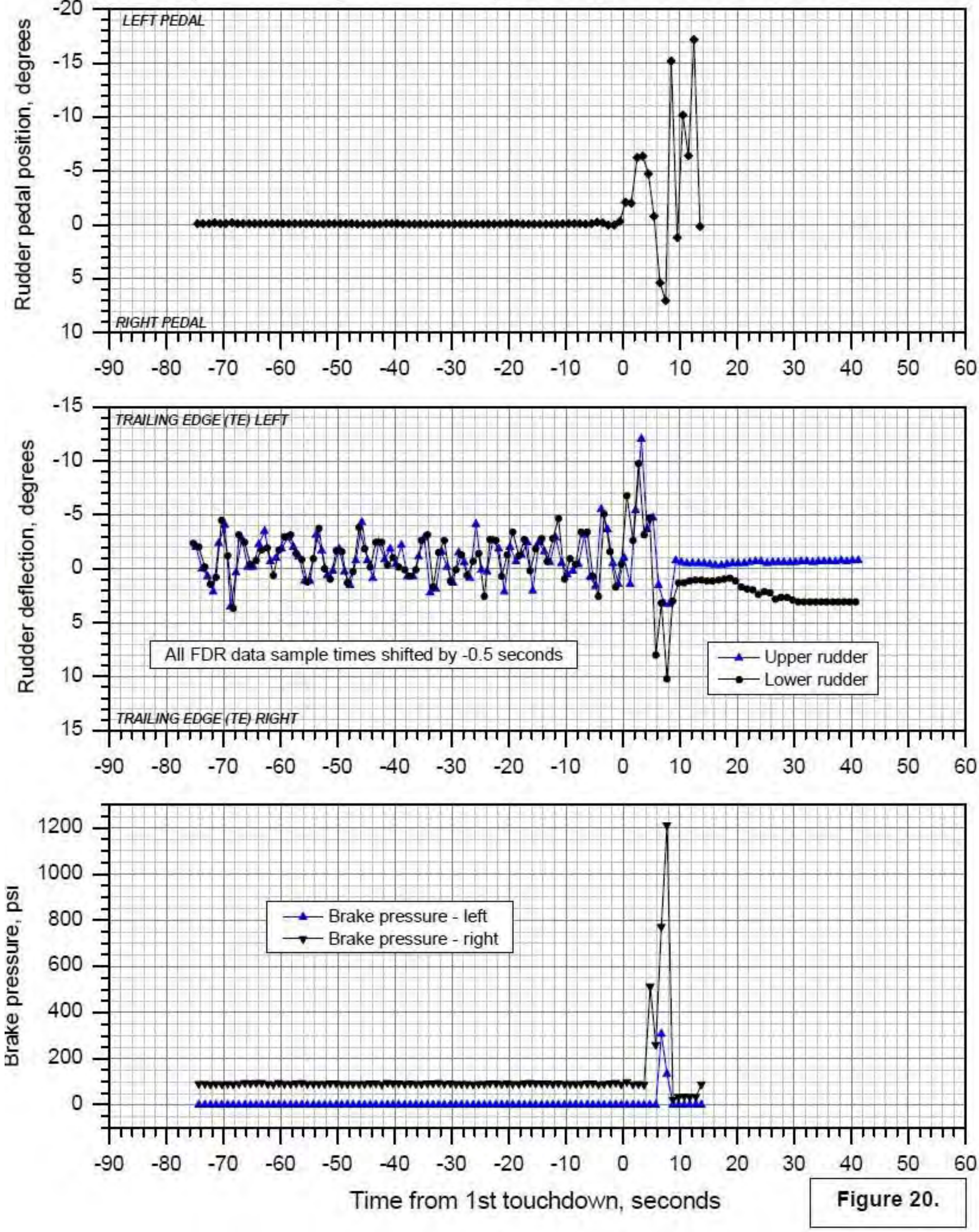

Figure 20.

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[redacted] Gear and crew heights

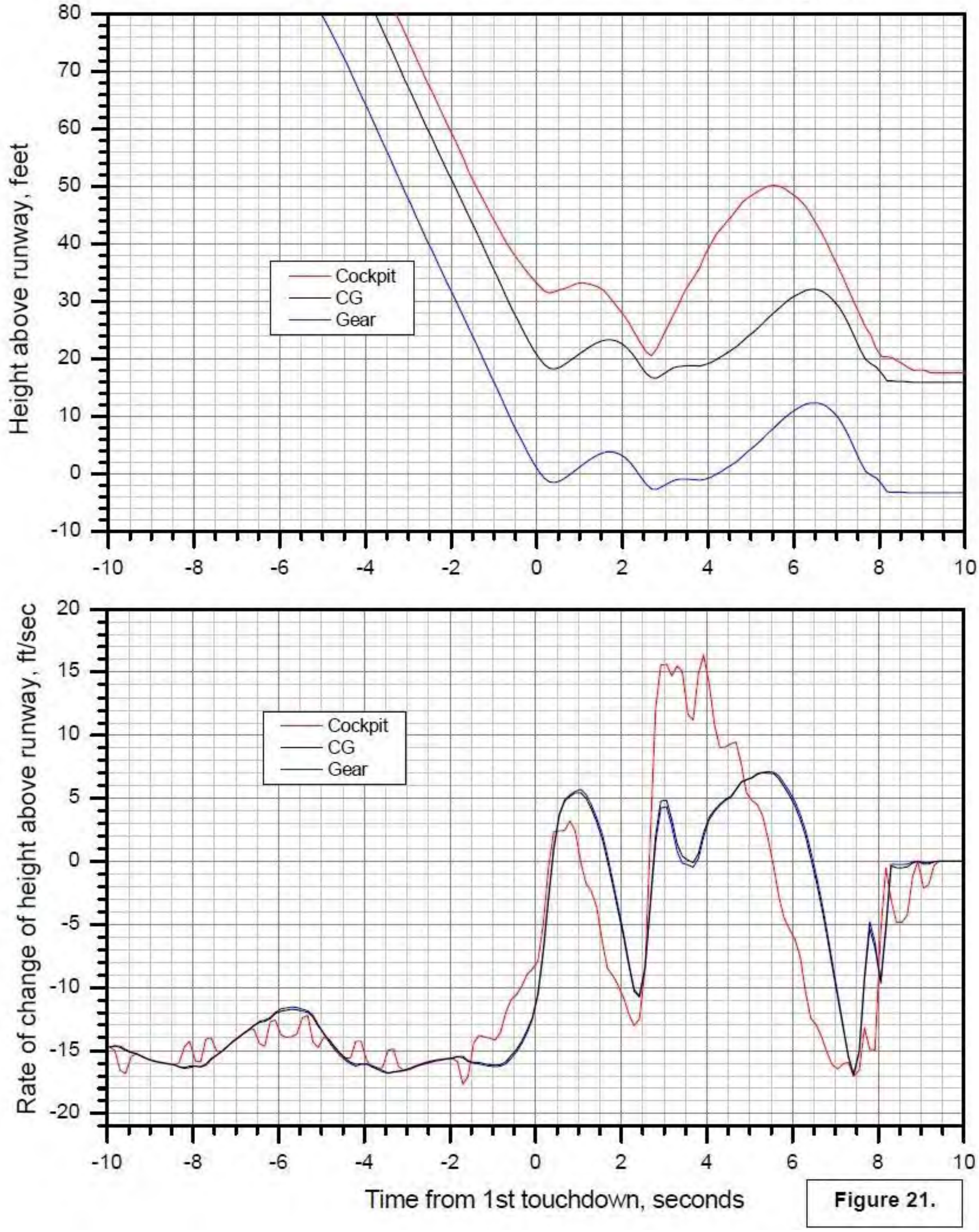

Figure 21.

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