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# FINAL INVESTIGATION REPORT

# ON OVERRUN INCIDENT INVOLVING

# FEDEX EXPRESS MD-11 AIRCRAFT FDX5033

# AT MUMBAI ON 03rd June 2020

**AIRCRAFT ACCIDENT INVESTIGATION BUREAU**
**MINISTRY OF CIVIL AVIATION**
**GOVERNMENT OF INDIA**

# FOREWORD

*In accordance with Annex 13 to the Convention on International Civil Aviation Organization (ICAO) and Rule 3 of Aircraft (Investigation of Accidents and Incidents), Rules 2017, the sole objective of the investigation of an accident /incident shall be the prevention of accidents and incidents and not to apportion blame or liability. The investigation conducted in accordance with provisions of the above said rules shall be separate from any judicial or administrative proceedings to apportion blame or liability.*

*This document has been prepared based upon the evidences collected during the investigation, opinion obtained from the experts and laboratory examination of various components. Consequently, the use of this report for any purpose other than for the prevention of future accidents or incidents could lead to erroneous interpretations.*

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# GLOSSARY

| | | |
|---|---|---|
| AAIB | : | Aircraft Accident Investigation Bureau, India |
| AFM | : | Aircraft Flight Manual |
| AMSL | : | Above Mean Sea Level |
| APS | : | Airplane Performance Software |
| ARC | : | Airworthiness Review Certificate |
| ASR | : | Airport Surveillance Radar |
| ATPL | : | Air Transport Pilot Licence |
| ATC | : | Air Traffic Control |
| AUW | : | All Up Weight |
| C of A | : | Certificate of Airworthiness |
| C of R | : | Certificate of Registration |
| CAR | : | Civil Aviation Requirements |
| CCTV | : | Closed Circuit Television |
| CPL | : | Commercial Pilot License |
| CVR | : | Cockpit Voice Recorder |
| FDR | : | Digital Flight data Recorder |
| DATIS | : | Digital Automatic Terminal Information Service |
| DGCA | : | Directorate General of Civil Aviation, India |
| FAA | : | Federal Aviation Administration |
| FO | : | First Officer |
| FCOM | : | Flight Crew Operating Manual |
| FCTM | : | Flight Crew Training Manual |
| FL | : | Flight Level |
| IATA | : | International Air Transport Association |
| ICAO | : | International Civil Aviation Organization |
| IFR | : | Instrument Flight Rules |
| IMC | : | Instrument Meteorological Conditions |
| ILS | : | Instrument Landing System |
| MEL | : | Minimum Equipment List |
| MLG | : | Main Landing Gear |
| NM | : | Nautical Miles |
| PF | : | Pilot Flying |
| PIC | : | Pilot in Command |
| PM | : | Pilot Monitoring |
| QRH | : | Quick Reference Handbook |
| RA | : | Radio Altitude |
| RESA | : | Runway End Safety Area |
| RWY | : | Runway |
| SB | : | Service Bulletin |
| SAFO | : | Safety Alerts for Operators |
| SAGA | : | Surface Awareness Guidance at Airport |
| TWR | : | Tower |
| TXY | : | Taxiway |
| VFR | : | Visual Flight Rules |
| VMC | : | Visual Meteorological Conditions |
| UTC | : | Coordinated Universal Time |

# SYNOPSIS

FedEx Express operated its flight FDX5033 from Bangalore to Mumbai on 03rd June 2020. RWY in use at Mumbai was RWY14. After landing, when FDX5033 was near the TXYE1 at end of RWY14, TWR controller issued clearance to vacate left via E1. But FDX5033 reported that it is unable to take left turn on RWY 14 and reported overrun. Immediately Tower controller issued instruction to aircraft to hold position. In coordination with Apron control & Ground FDX5033 was advised to switch off engines. Subsequently, FDX5033 reported poor braking action. At 0724 UTC, RWY 14/32 was made available & it was fit for operations. At 0733 UTC, FDX5033 was fully parked. There was no damage.

# FINAL INVESTIGATION REPORT ON OVERRUN INCIDENT TO FEDEX EXPRESS MD-11 AIRCRAFT FDX5033 AT MUMBAI ON 03 JUN 2020

| | | | |
|---|---|---|---|
| 1. | Aircraft | : | **McDonnell Douglas** |
| | Type | : | **MD-11** |
| | Nationality | : | **United States of America** |
| | Registration | : | **FDX 5033** |
| 2. | Operator | : | **FEDEX Express** |
| 3. | Pilot – in –Command | : | **ATPL holder on type** |
| | Extent of injuries | : | **Nil** |
| 4. | First Officer | : | **ATPL Holder on type** |
| | Extent of injuries | : | **Nil** |
| 5. | Passengers on Board | | **Nil** |
| 6. | Last point of Departure | | **Bengaluru Airport (India)** |
| 7. | Intended landing Place | | **Mumbai Airport (India)** |
| 5. | Place of Incident | : | **Mumbai Airport (Runway 14 / 32)** |
| | Coordinates of Site | | **19$^o$ 5" 17.916" N 72$^o$ 50' 51.72" E** |
| 6. | Date & Time of Incident | : | **03 Jun 2020 & 0640 UTC** |
| 7. | Phase of operation | : | **Landing Roll** |
| 8. | Type of Incident | : | **Runway Overrun** |

(ALL TIMINGS IN THE REPORT ARE IN UTC UNLESS OTHERWISE SPECIFIED)

# 1. FACTUAL INFORMATION

## 1.1 History of the Flight

FedEx Express MD11 aircraft while operating a Cargo flight FDX5033 from Bangalore to Mumbai on 03rd June 2020 was involved in an incident of Runway overrun while landing on RWY 14 at Mumbai in rain.

The aircraft was radar vectored for an ILS approach for Runway 14 at Mumbai. The aircraft was stabilized for the approach by 1000′ with landing configuration selected as Flaps 50.

Reported winds as per the METAR of 0600 UTC were 030 degrees at 10 Kts gusting to 20 Kts. This reported wind results in an approximately 5 Kts tailwind component on Runway 14. At time 06:39 UTC, the aircraft came in contact with Mumbai tower. It was established on ILS RWY 14 and instructed to continue approach and wind information of 030 degrees at 10 Kts gusting to 20 Kts were passed. Aircraft read back instructions correctly. At time 06:40 UTC, tower controller issued landing clearance to the aircraft with winds reported as 030 degrees at 10kts. Aircraft read back instructions correctly.

The autopilot was selected throughout the descent phase and during approach the second autopilot was also coupled for the ILS approach. At 500 feet the autopilot was disengaged. The aircraft crossed the landing threshold at approximately 50 feet altitude and the flare manoeuvre was initiated, however due to the long flare manoeuvre consumed 2608′ of the runway prior to all main landing gears making contact with runway leaving 5499′ of runway remaining.

Once the aircraft touchdown occurred, the speed brakes deployed automatically and reverse thrust was applied 2 seconds after touchdown. The reverse thrust was maintained at full till 80 Kts and then were beginning to stow but were redeployed to maximum reverse thrust. The left engine suffered what appears to be an engine stall with visible flames near the exhaust after the reverse thrust was redeployed. The airplane maintained runway heading with normal variations until the groundspeed reached 50 Kts. At 50 Kts a left turn was initiated.

After landing, when the aircraft was near the TXY E1, TWR controller issued clearance to the aircraft to vacate left via E1. But the aircraft reported that it is unable to take left turn on RWY 14 and reported overrun.

Immediately Tower controller advised the aircraft to hold position. The aircraft had exited the prescribed dimensions of RWY 14.

Tower controller instructed aircraft to switch off the engines. Later flight crew of the aircraft reported that braking action was poor and requested tow tractor for proceeding to bay. The aircraft was towed to parking stand. There was no damage to aircraft or injury to any persons. Flight crew again reported on RT that braking action was NIL.

Subsequently, preliminary incident report submitted by the ANS Service provider is as: "*FDX 5033 established on ILS RWY 14 , after landing on RWY 14 was instructed to vacate left via E1 but FDX5033 reported it has overrun and unable to make left turn and was observed to be turning right. The vacation to right was not possible as it would have led to wrong apron and also since aircraft was visually observed to be stationary at the end of RWY, aircraft was instructed to hold position and follow me jeep was called to the site. At time 0646 UTC in co-ordination with apron and follow me jeep aircraft was instructed to switch off engine. At time 0648 UTC follow me jeep reported to ground that aircraft has entered RESA RWY 14 but is on hard surface and no damage to the aircraft. Later aircraft was changed over to ground frequency. At time 0714 aircraft was towed to stand G-3 and parked at 0733 UTC. At 0724 UTC follow me jeep inspected RWY 14-32 and found fit for normal operation. No contamination was found on runway*".

## 1.2 Injuries to Persons

| INJURIES | Crew | Passengers | Others |
|---|---|---|---|
| Fatal | Nil | Nil | Nil |
| Serious | Nil | Nil | Nil |
| None | 02 | Nil | Nil |

## 1.3 Damage to Aircraft

Nil

## 1.4 Other Damage

Nil

## 1.5 Personnel Information

The crew were operating the aircraft under the FAA regulations.

## 1.6 Aircraft Information

| | | |
|---|---|---|
| Aircraft Model | : | **MD-11-F** |
| Aircraft S. No. | : | **48421** |
| Year of Manufacturer | : | **1991** |
| Name of Owner | : | **FedEx Express Corporation** |
| C of R | : | **Valid** |
| C of A | : | **Valid** |

| | | |
|---|---|---|
| Category | : | **Cargo / Passenger** |
| Validity of A R C | : | **Valid** |
| Aircraft Empty Weight | : | **262773 Lb** |
| Maximum Takeoff weight | : | **630500 Lb** |
| Max Usable Fuel | : | **256886 lb** |
| Max Payload with full fuel | : | **110861 lb** |
| Empty Weight C.G | : | **30.81 % MAC** |
| Total Aircraft Hours | : | **89578:03** |
| Last major inspection | : | **"C" Check on 24 Jan 2019 at 86438:11 Hrs and 19761 Cycles** |
| Compliance status of AD, SB, Modification | : | **All Complied** |
| Type of Engine(s) | : | **CF6-80C2D1F GE Engine** |

### *1.6.1 MD-11/MD-10 Flight Manual*

The relevant extract of the Flight Manual is as follows:

***Airplane Performance Software (APS)***

APS is the primary source the Flight Crew uses to determine takeoff and landing performance data and to calculate Contingency Weight & Balance data. It is accessed through the Performance application on the Electronic Flight Bag (EFB). APS can also be used for Fuel Service Form verification.

APS uses a database of airport information that includes field elevations, runway identifiers, lengths and slopes, and departure obstacles along the engine-out departure path. This database, along with the APS software, is maintained by FedEx Development and Operations Engineering and is updated every 28 days.

Global Operations Control (GOC) possesses software identical to that used on the EFB. If the EFB application is unavailable, GOC may transmit via ACARS, radio, SATCOM, or phone the required performance data for dispatch, takeoff and/or landing. In addition, performance data may be obtained from another FedEx aircraft APS.

***LND Module Inflight***

The Landing Performance (LND) module computes data for Dispatch and In-Flight Landing Performance Assessment. Dispatch Landing Performance is based on data from the FAA-approved AFM. In-flight Landing Performance Assessment data is based on auto-braking data from the FAA-approved AFM and also incorporates aircraft manufacturer data for landing on contaminated runways.

The Landing Performance module can be accessed any time the LND button is active. Click the LND button to access the LND module. Use the INFLIGHT and DISPATCH buttons to select the desired module. A short, vertical green line will identify the currently selected module; the default is INFLIGHT.

The airport and all associated inputs and selections made in the LND module are unique to the LND module and are not referenced by any other module. Likewise, the airport and all associated inputs and selections made in the INFLIGHT (DISPATCH) module are unique to the INFLIGHT (DISPATCH) module and are not referenced by the other module.

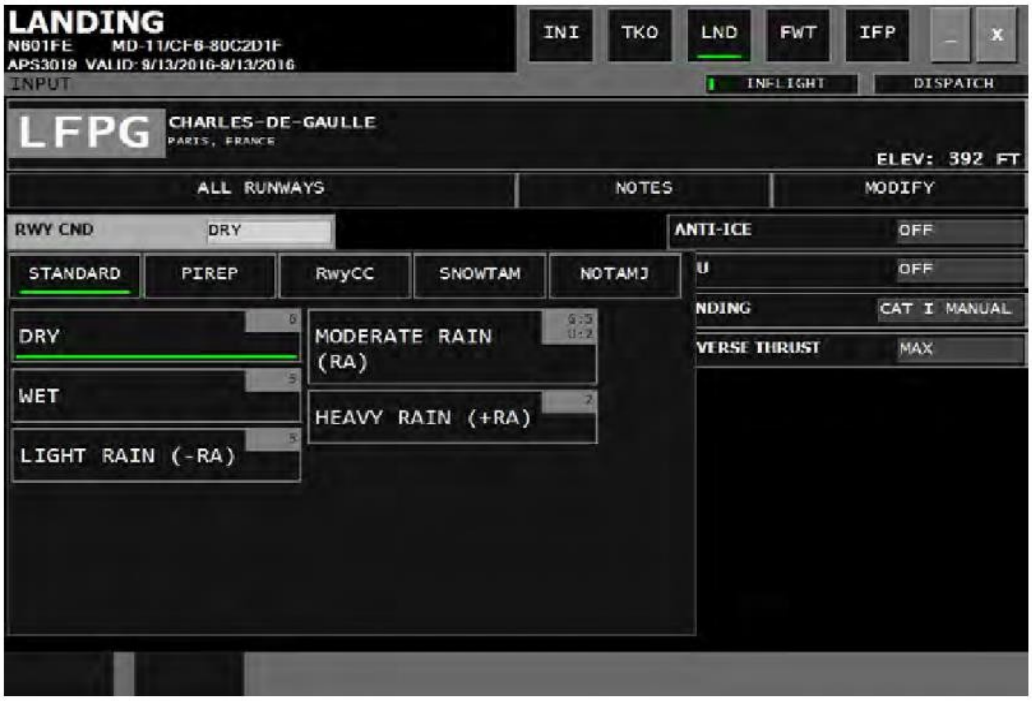


**FIG-1:** INFLIGHT Landing Performance Assessment Module (The image shows the APS capability to input Runway condition as DRY / WET etc.)


**FIG-2**: INFLIGHT Landing Performance Assessment Module (The image shows the APS capability to input Runway condition based on Pilot Report)

*Runway Surface Condition (RWY CND) Entry*

RWY CND is the Runway Surface Condition; the default is DRY. Click the RWY CND entry to display the Runway Surface Condition selection sub-menu that is divided into five categories. Click the appropriate category, and then click the appropriate condition to select it.

*WIND Entries*

Click the wind Entries to input the DIRECTION, SPEED and GUST of the reported surface wind. Wind DIRECTION is entered in whole degrees. The MAG[netic] and TRUE North buttons are used to select the wind direction reference; the default is MAG. Click the desired selection to change the wind direction reference selection; alternatively, append "M" or "T" to the DIRECTION input value, e.g. "250T", to select the units.

The wind SPEED and GUST are input in whole numbers. The GUST value is the maximum wind speed, not an increment above the reported steady state speed. No GUST input is required if it is not applicable.

The Knots, KM/H (kilometers per hour), M/S (meters per second), and MPH (miles per hour) buttons are used to select the units of the wind SPEED and GUST; the default is Knots. Click on the desired selection to change the units; alternatively, append "K" to the SPEED or GUST input value to select Knots, e.g. "15K".

Input shortcuts allow successive input of multiple wind entries. For example, click wind DIRECTION, input "250T/15/26", and click enter to yield a wind direction of 250 degrees TRUE, SPEED of 15, and GUST of 26. Similarly, click wind SPEED, input "12/30", and click enter to yield a wind SPEED of 12, and GUST of 30.

Alternatively, in lieu of using a forward slash (/) use the green "Enter-and-Continue-to-Next-Entry" button (white triangle point down) to complete the data input and automatically select the subsequent entry for data input.

***Note***: INFLIGHT LND calculations do not take credit for the headwind component of the GUST value, but the tailwind component of the GUST value is utilized.

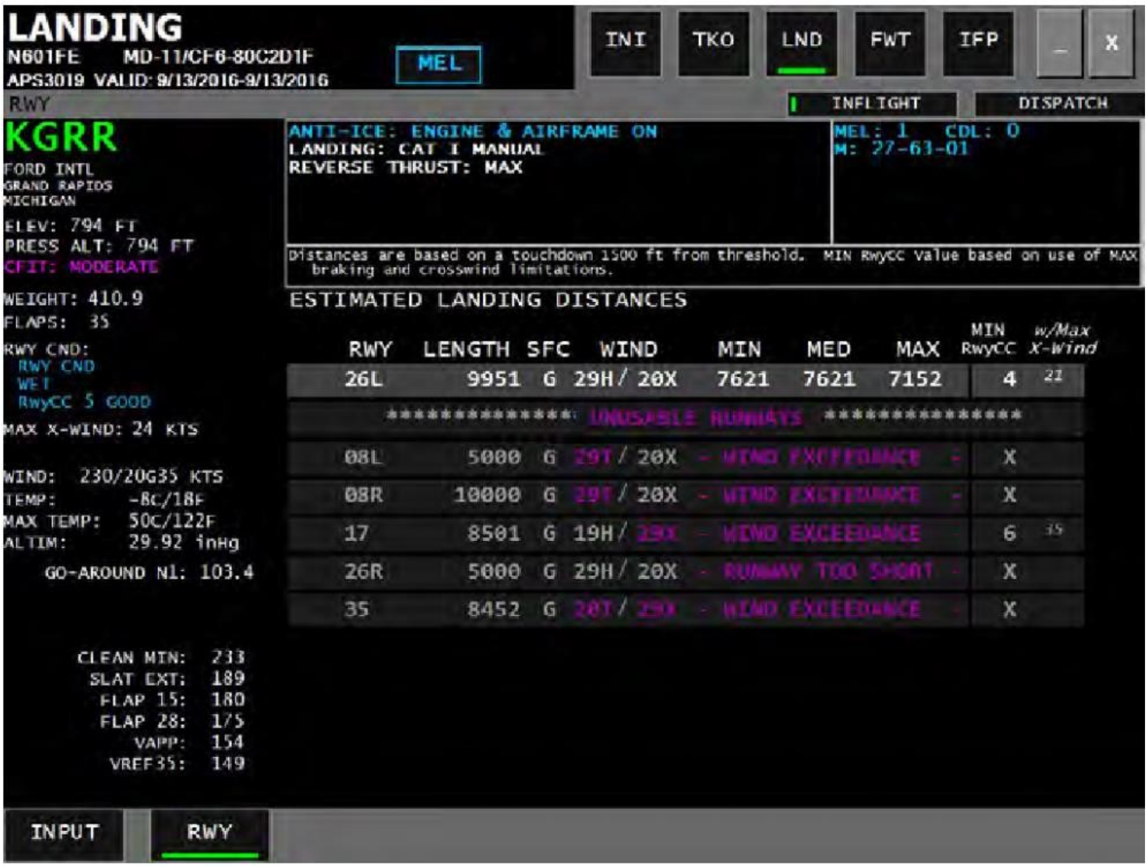


**Fig – 3**: INFLIGHT LND RWY Output Screen

Multiple examples of the INFLIGHT LND RWY Output Screen are provided in fig-3 to depict the variety of possible display features.

***Note:*** The availability of only one runway in the following example that represents a contaminated runway condition (wet).

### *1.6.2 MD-11/MD-10 Flight Training Manual*

The relevant portion of the Flight Training Manual is as follows:

***Autospoilers***

Auto ground spoilers normally deploy at main wheel spin up. For MD-11, two-step auto ground spoilers are fully deployed after nose wheel touchdown.

***Rollout***

As nose wheel is lowered to the runway, deploy reversers on all three engines simultaneously. A momentary pause will be encountered at interlock stop on engines 1 and 3, and then reverse thrust may be selected to desired level. Engine 2 will provide only idle reverse thrust until nose wheel strut compression. "

"PM: Monitor airspeed during deceleration. At 80 knots, call "80 knots," at 60 knots, call "60 knots."

At 80 knots, smoothly move the reverse thrust levers toward the reverse idle detent, so as to be at idle forward thrust by 60 knots.

Autospoilers, if available, will be armed for landings.

***Auto Brakes Operation During Landing Rollout***

For a normal landing, auto brake operation may be terminated either by stowing ground spoilers or pressing brake pedals.

The PF may smoothly deactivate auto brakes by stowing ground spoilers at or below 60 knots. The auto brakes are not disarmed; the ABS DISARM lights will not illuminate. AUTO BRAKE is still armed to activate if ground spoilers are again deployed.

***Caution*:** Avoid unnecessary use of the AUTO BRAKE mode selector during landing roll; the anti-skid may be inadvertently turned off, resulting in blown tyres.

***Maximum Auto Brake - Technique***

Consider using maximum auto brakes for landing, if available, for adverse conditions (e.g., wet/slippery runways, high crosswinds, etc.).

**1.7 Meteorological Information**

The relevant METARs are as follows:

030730Z 02020G30KT 2200 -RA FEW012 SCT018 FEW030CB OVC080 27/24 Q0996 TEMPO 1500 SHRA=

030700Z 02013G23KT 2200 -RA FEW012 SCT018 FEW030CB OVC080 27/25 Q0996 TEMPO 1500 SHRA=

030630Z 03011G21KT 2200 -RA FEW012 SCT018 FEW030CB OVC080 27/25 Q0997 TEMPO 1500 SHRA=

030600Z 03010G20KT 2200 -RA FEW012 SCT018 FEW030CB OVC080 27/25 Q0998 TEMPO 1500 SHRA=

The reported Runway condition and associated weather report as per DATIS on 03 June 2020 is as follows:

| S.No. | DATIS Time (UTC) | RWY Condition Reported | Wx Reported |
|---|---|---|---|
| 1. | 0404 | RWY 14 WET | Light Rain |
| 2. | 0507 | RWY 14 WET | Light Rain |
| 3. | 0542 | RWY 14 WET | Light Rain |
| 4. | 0605 | RWY 14 WET | Light Rain |
| 5. | 0627 | RWY 14 WET | Light Rain |
| 6. | 0655 | RWY 14 WET | Light Rain |
| 7. | 0729 | RWY 14 WET | Light Rain |

## 1.8 Aids to Navigation

Mumbai airport is equipped with VOR (frequency 116.60 MHz), DME (frequency 1200/1137 MHz), NDB (frequencies 396 kHz), ASDE (frequency 9375 MHz). PAPI & ILS Cat-II lighting is installed on Runway 27. PAPI &ILS Cat-I lighting is installed at 09 & 14 and SALS (Simple Approach Lighting System) is installed at Runway 32. All nav Aids were functioning normally. No defect reported.

## 1.9 Communications

Positive two way communication between ATC and aircraft was established and maintained throughout. Tape Transcript for the communication with the Tower is as below.

| TIME (HHMMSS) | FROM | TEXT |
|---|---|---|
| | | 118.1MHZ (TOWER) |
| 063942 | FDX5033 | TWR GOOD AFTERNOON FDX5033 HEREBY 7 MILES ILS14. |
| 063946 | TWR | FDX5033 HEAVY MUMBAI TWR CONTINUE APPROACH RWY 14 WIND 030 DEGREE 10 KTS GUSTING 20 KTS |
| 063954 | FDX5033 | ROGER CONTINUE APPROACH FDX5033 |
| 064033 | TWR | FDX5033 RWY 14 CLEARED TO LAND WIND 030 DEGREE 10 KTS RWY WET |
| 064048 | FDX5033 | ROGER CLEARED TO LAND 14 FDX5033 HEAVY |
| 064231 | TWR | FDX5033 VACATE VIA E1 |
| 064243 | TWR | FDX5033 GROUND FDX5033 TWR |
| 064248 | FDX5033 | FDX5033 STANDBY |
| 064303 | FDX5033 | FDX5033 WE OVERRUN STANDBY |
| 064307 | TWR | ROGER CONFIRM ABLE TO TAKE LEFT TURN |
| 064310 | FDX5033 | NEGATIVE LEFT TURN FDX5033 |
| 064315 | TWR | ROGER FOLLOW ME MUMBAI TOWER |
| 064338 | TWR | FDX5033 CONFIRM ASSISTANCE REQUIRED SIR |
| 064342 | FDX5033 | FDX5033 WE ARE GONE CLEAR RIGHT TURN OK THANKS YOU |
| 064400 | TWR | FDX5033 TAKE A LEFT TURN SIR |
| 064404 | FDX5033 | RIGHT NOW WE CAN HOLD CAN DO BEST RIGHT NOW STAND |
| 064408 | TWR | FDX5033 HOLD POSITION SIR HOLD POSITION FDX5033 |
| 064412 | FDX5033 | FDX5033 |
| 064419 | TWR | FDX5033 HOLD POSITION |
| 064421 | FDX5033 | HOLD POSITION FDX5033 |
| 064453 | FM 3 | NAMASKAR FM 3 |
| 064454 | TWR | FM TWR |
| 064455 | FM | REQUEST CROSS RWY 14 W4 E 5 |
| 064458 | TWR | APPROVED |
| 064500 | FM | CONFIRM APPROVED |
| 064501 | TWR | AFFIRM APPROVED |
| 064502 | FM 3 | APPROVED REPORT CLEAR FM3 |
| 064600 | TWR | FDX5033 MUMBAI TWR |
| 064603 | FDX5033 | FDX5033 GO AHEAD |
| 064604 | TWR | FDX5033 YOU HAVE TO SWITCH OFF YOUR ENGINE NOW |
| 064607 | FDX5033 | ALL RIGHT WE TURN OFF THE ENGINE FDX5033 |

| | | |
|---|---|---|
| 064622 | FDX5033 | TWR FDX5033 WE JUST WITH THE JUST…….. TRY TO MAKE THAT TURN BUT THAT WAS TOO WET AND WE ARE TOO HEAVY |
| 064630 | TWR | ROGER |
| 064634 | TWR | CONFIRM BREAKING ACTION WAS BAD SIR |
| 064637 | FDX5033 | BREAKING ACTION WAS POOR AND AIRPLANE IS OK |
| 064652 | FDX5033 | WE ARE GONNA NEED TOW TRUCK TO COME PUSHUS BACK SO WE CAN TAXI |
| 064658 | TWR | ROGER WE ARE COORDINATING FOR TRUCK STANDBY |
| 064703 | FDX5033 | STANDBY FDX5033 |
| 064704 | TWR | CONFIRM YOUR ENGINE ARE SWITCHED OFF NOW |
| 064707 | FDX5033 | WE ARE MORE ENGINE STANDBY |
| 064709 | TWR | ROGER REPORT WHEN BOTH ENGINE SWICHED OFF |
| 064712 | FDX5033 | ROGER |
| 064745 | FDX5033 | AND NOW ENGINE IS SHUTDOWN FDX5033 |
| 064747 | TWR | ROGER STANDBY SIR |
| 064850 | FDX5033 | AND TWR BREAKING ACTION WAS NIL |
| 064853 | TWR | COPIED SIR |
| 065227 | FDX5033 | TWR FDX5033 YOU HAVE FREQUENCY TO CONTACT FOR GROUND |
| 065233 | FM 3 | MUMBAI TWR FM3 |
| 065234 | TWR | FM 3 GO AHEAD |
| 065235 | FM 3 | FDX ENGINEER ON BOARD WILL BE REACHING SHORTLY NEAR THE AIRCRAFT |
| 065239 | TWR | ROGER COPIED |
| 065240 | TWR | FDX5033 CONFIRM COPIED |
| 065244 | FDX5033 | YO WE CAN SEE THE TRUCK COMING UP THANK YOU |
| 065245 | TWR | ROGER |

## 1.10 Aerodrome Information

The CSIA Mumbai (Reference point 19° 05' 30'' N 072° 51' 58'' E) is a licensed airport both for IFR and VFR traffic with IATA location Identifier code as BOM and ICAO location Indicator code is VABB. The elevation (AMSL) is 12.13 m (40 ft) with reference code as 4F.

The airport has two cross runways made of Asphalt. The principle dimensions of these runways are as given below: -

| RWY | TORA (m) | TODA (m) | ASDA (m) | LDA (m) | Displacement | RESA (m) |
|---|---|---|---|---|---|---|
| 09 | 3188 | 3188 | 3188 | 3048 | 140 | 240 x 120 |
| 27 | 3448 | 3448 | 3448 | 2965 | 483 | 240 x 120 |
| 14 | 2871 | 2871 | 2871 | 2471 | 400 | 90 x 90 |
| 32 | 2871 | 2871 | 2871 | 2673 | 198 | 150 x 100 |

***RWY Dimension***

*RWY 14-32:* 2871 m X 45 m (Shoulder of 15m either side)

***RWY Strip Dimension***

*RWY 14-32:* 2991 m X 300 m

***Stopway***

Not Available for RWY 14 & RWY 32

***RWY Threshold Elevation***

*RWY 14 THR*: 39.7 ft / 12.1 m

*RWY 32 THR:* 25.2 ft / 7.6 m

***Note:*** The RESA at Mumbai runway 14 / 32 meets the standards laid down by ICAO but does not meet the *Recommended Practice* as stated by ICAO. The *Recommended Practice* infer a desirable level of Safety versus the necessary requirements as listed in the *Standard.*

**1.10.1 Runway Layout**

The figure - 4 below shows the runway and taxiways for Runway 14.

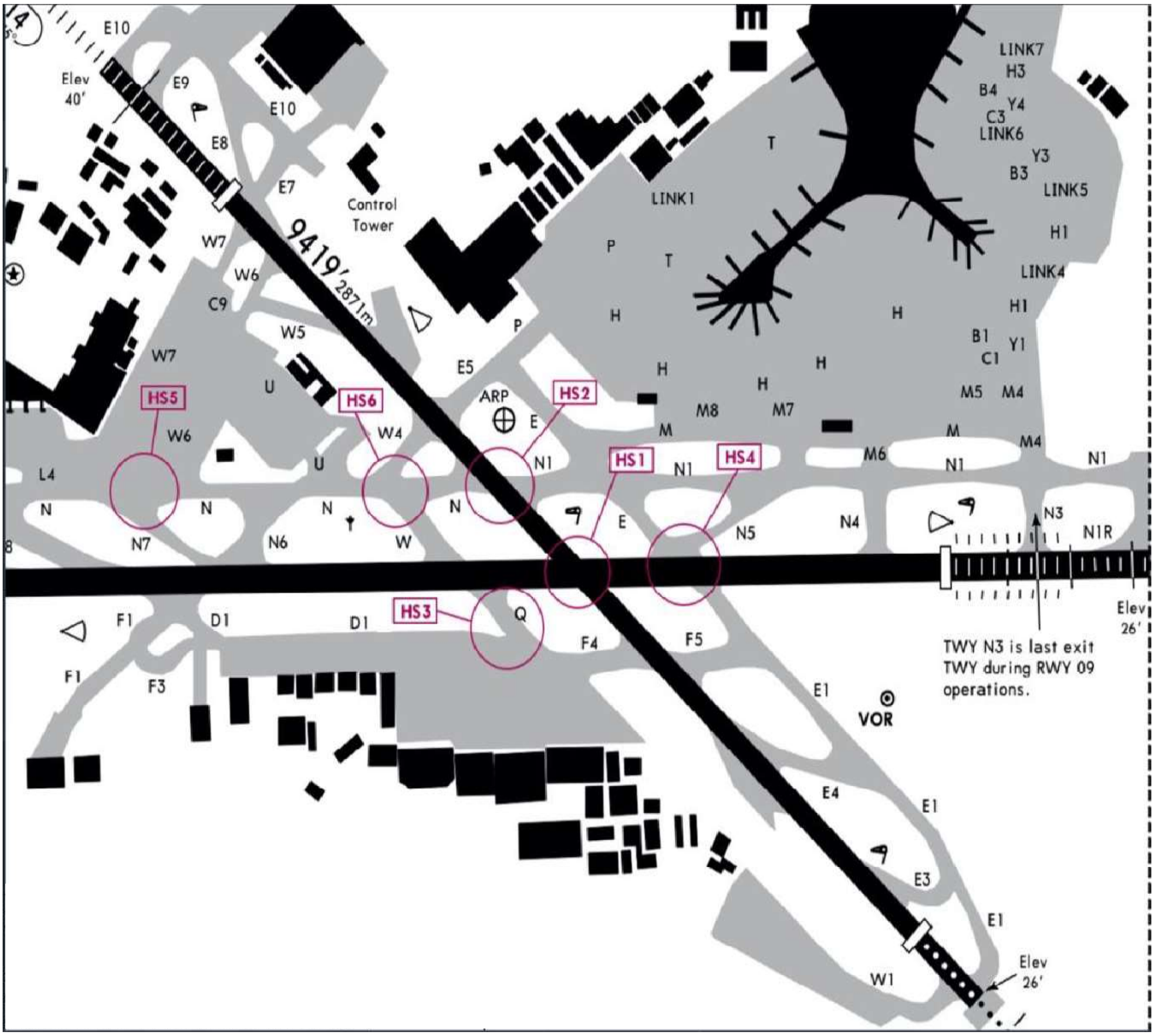


**Fig-4**: Image of Runway 14 (Runway & Taxiway)

### 1.10.2 Runway 14 Centre Line Elevation Plot

The figure - 5 show the profile and plan view as calculated based on elevation measurements of Runway 14.

Profile View

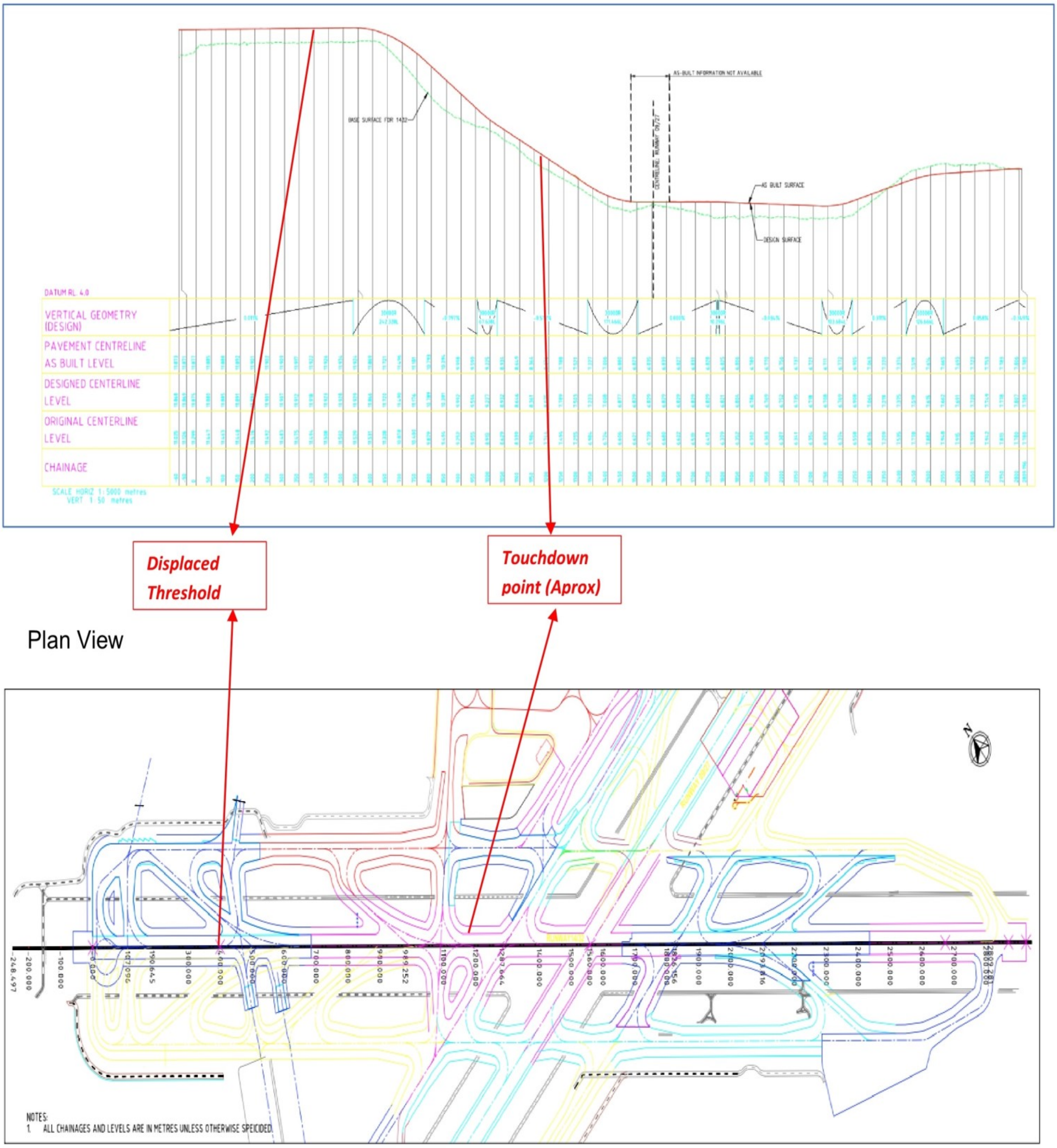


**Fig – 5**: Runway 14 Centre Line Elevation Plot

### 1.10.3 Runway Friction Test Graph

The figure - 6 to figure - 9 below are an extract of the graphical depiction of runway friction test carried out on 26 May 2020. The images indicate that towards the last 500m of runway 14, the friction measurement have touched Warning / Danger levels.

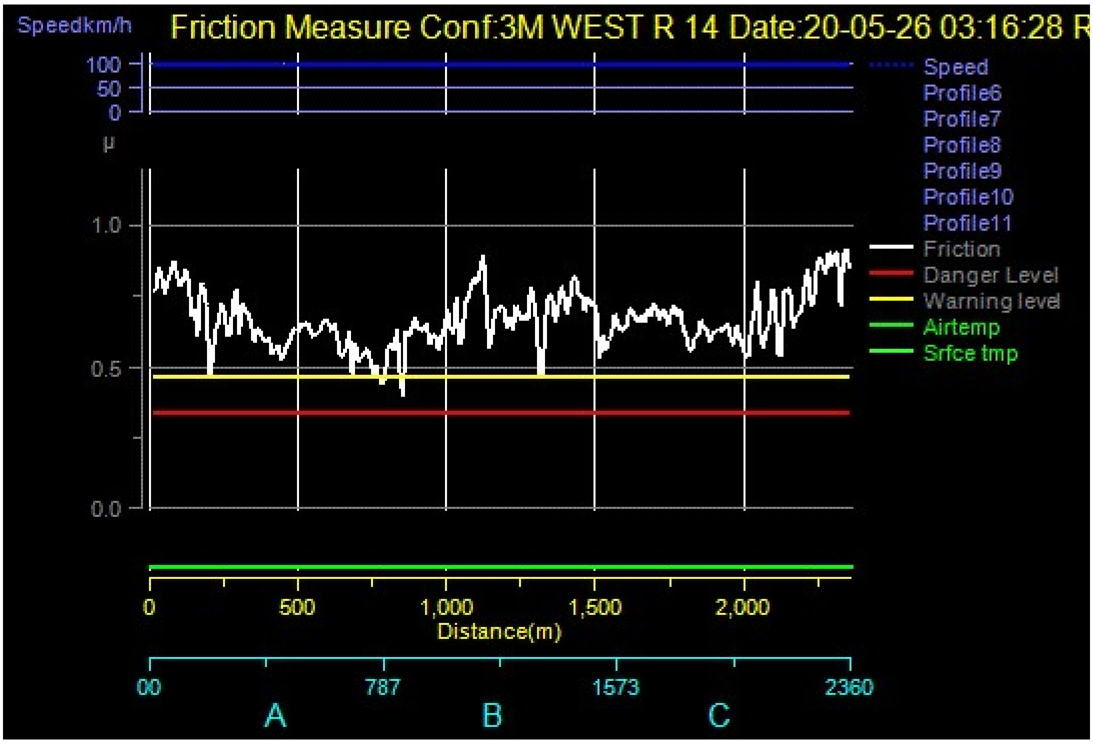


**Fig-6**: Friction Test Graph (03 Metre West of RWY 14)

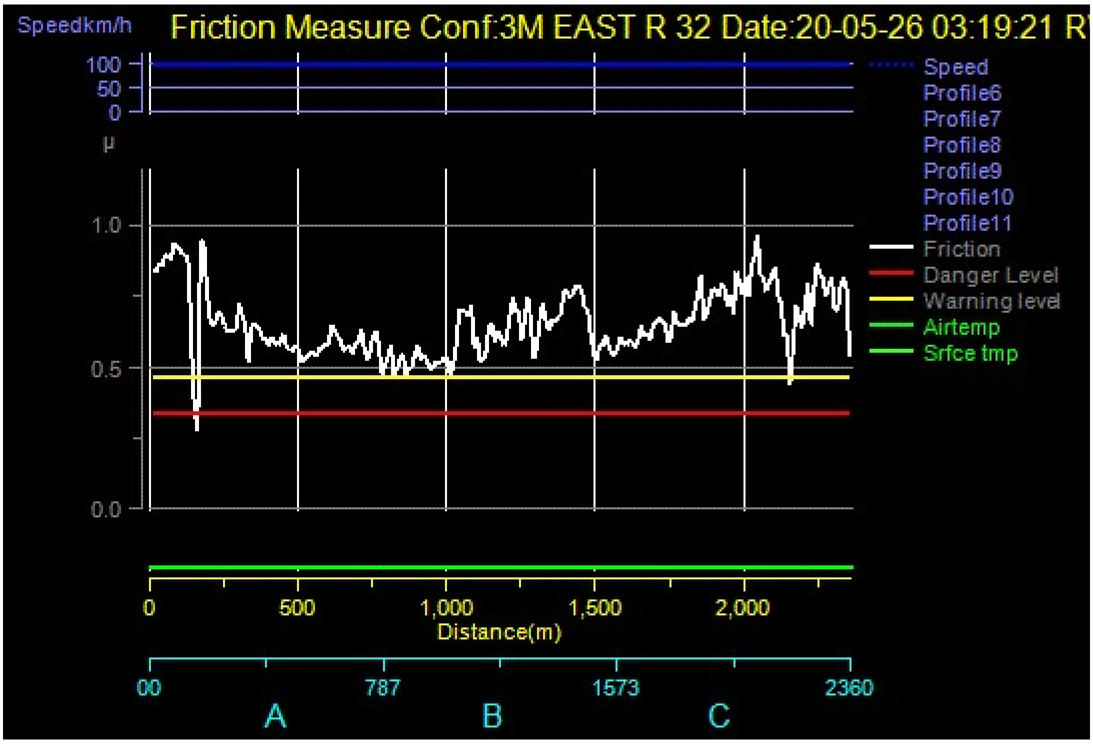


**Fig-7**: Friction Test Graph (03 Metre East of RWY 14)

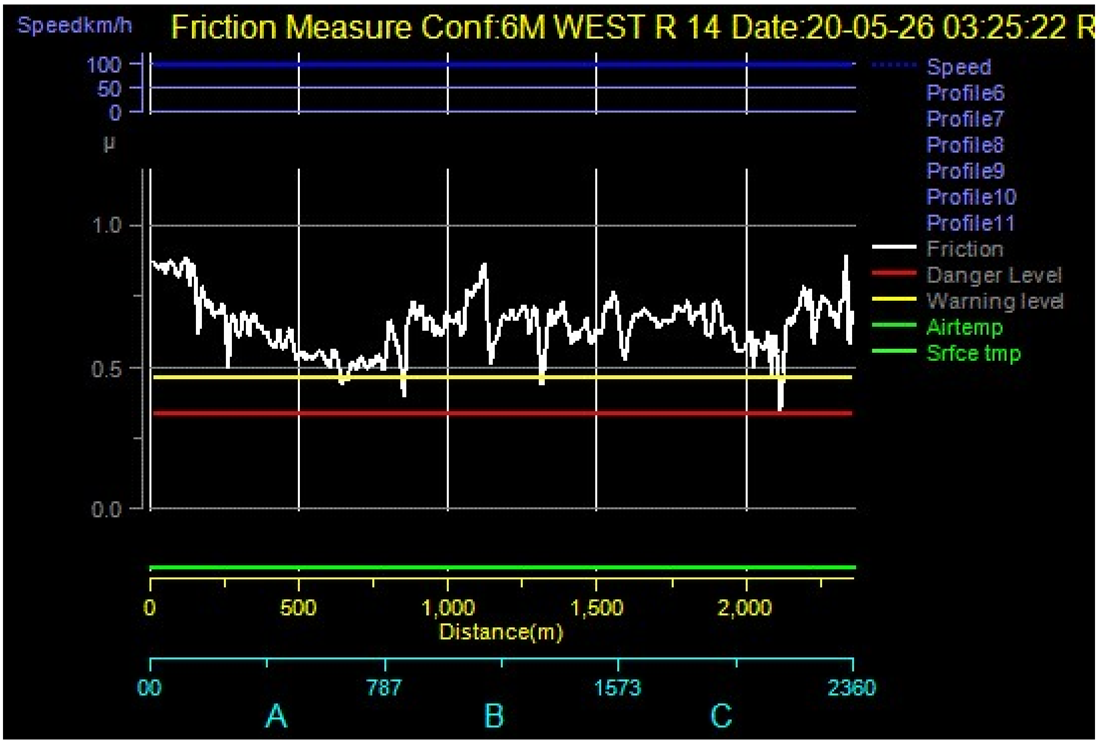


**Fig-8**: Friction Test Graph (06 Metre West of RWY 14)

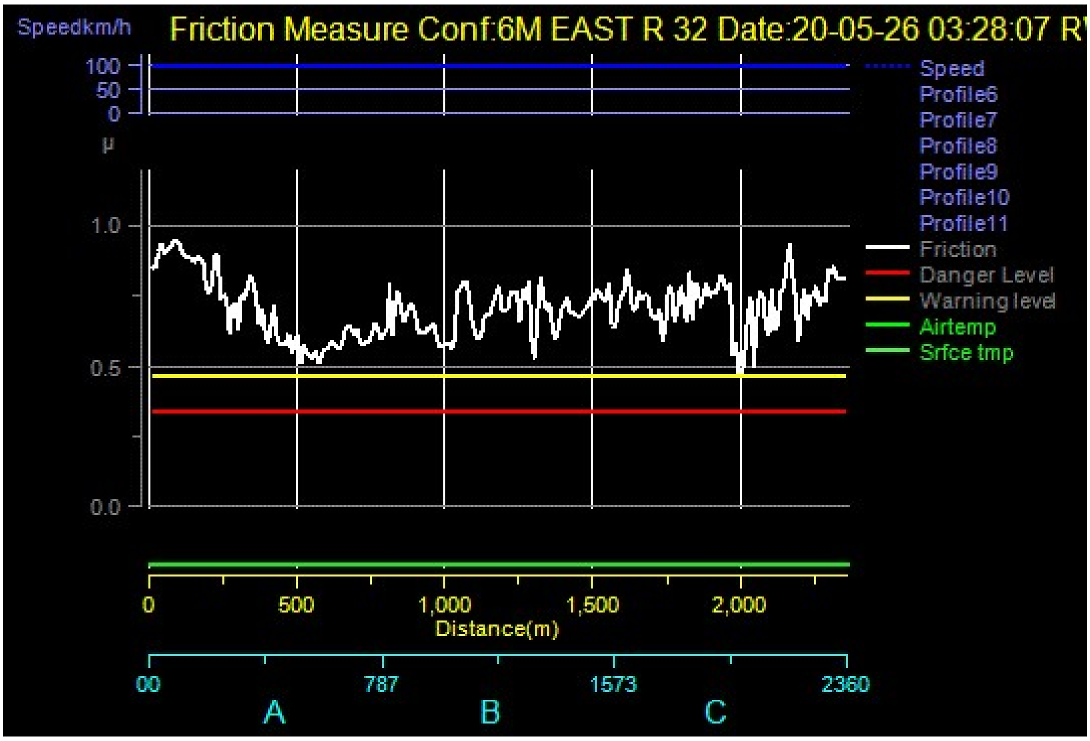


**Fig-9**: Friction Test Graph (06 Metre East of RWY 14)

### 1.10.4 Friction Test Report

The Aerodrome Operator conducted a friction test shortly after the incident. The Friction Test reports for the test just preceding this incident was carried out on 26 May 2020 and again after the Incident on 03 Jun 2020. The reports are as below:

***Test Report of 26th May 2021***

| Mumbai International Airport Ltd | FRICTION TEST REPORT<br>Department: AGM | Dc. No.: MIAL/AO-AGM/FMT/11/01<br>Date:- 27/08/2019 |
|---|---|---|

**Station:** CSMI Airport Mumbai **Region:** W.R. **Date of Test:** 26-05-2020

1. **Test equipment used:** Airport Surface Friction Tester (ASFT) VOLVO XC- 60
2. **Details of Runway**
   Runway : 14-32
   Length : 2871m
   Width : 45m
   Date of last Re-carpeting : Overlay Completion 30th May 2016
   Average number of Aircraft movement per day: 15
3. **Calibration of Test equipment** : Calibrated and found o.k. on dated 25/05/2020
4. **Parameter setting.**
   Measuring Speed : 95 Kmph
   Water jet used : Yes
   Mode set : ICAO
   Distance Measured : 2360m
   Measurement Taken : 3m and 6m from center line of RWY 14-32 (L/R)
5. **Test Result (Friction Co-Efficient – Average Values)**

| Distance From Centerline | Section A | Section B | Section C | Total Average | Remarks |
|---|---|---|---|---|---|
| 3 m west | .65 | .67 | .70 | .67 | 14 |
| 3 m east | .65 | .61 | .71 | .66 | 32 |
| | .65 | .64 | .70 | .66 | Average |
| 6 m west | .64 | .66 | .66 | .65 | 14 |
| 6 m east | .71 | .69 | .73 | .71 | 32 |
| | .67 | .67 | .69 | .68 | Average |

6. **Average value of Test Runs Result:** Pre Test .61 Post Test .61
7. **Reference**

| Test equipment | Test tyre Type pressure (kpa) | | Test speed (km/h) | Test water depth | Design objective for new surface | Maintenance planning levels | Minimum friction level |
|---|---|---|---|---|---|---|---|
| (1) | (2) | | (3) | (4) | (5) | (6) | (7) |
| Surface Friction Tester Vehicle | B | 210 | 65 | 1.0 | 0.82 | 0.60 | 0.50 |
| | B | 210 | 95 | 1.0 | 0.74 | 0.47 | 0.34 |

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***Test Report of 03 Jun 2021***

| Mumbai International Airport Ltd | FRICTION TEST REPORT<br>Department: AGM | Dc. No.: MIAL/AO-AGM/FMT/11/01<br>Date:- 27/08/2019 |
|---|---|---|

**Station:** CSMI Airport Mumbai **Region:** W.R. **Date of Test:** 03-06-2020

1. **Test equipment used:** Airport Surface Friction Tester (ASFT) VOLVO XC- 60
2. **Details of Runway**

   Runway : 14-32

   Length : 2871m

   Width : 45m

   Date of last Re-carpeting : Overlay Completion 30th May 2016

   Average number of Aircraft movement per day: 15
3. **Calibration of Test equipment** : Calibrated and found o.k. on dated 03/06/2020
4. **Parameter setting.**

   Measuring Speed : 95 Kmph

   Water jet used : Yes

   Mode set : ICAO

   Distance Measured : 2360m

   Measurement Taken : 3m and 6m from center line of RWY 14-32 (L/R)
5. **Test Result (Friction Co-Efficient – Average Values)**

| Distance From Centerline | Section A | Section B | Section C | Total Average | Remarks |
|---|---|---|---|---|---|
| 3 m west | .66 | .59 | .64 | .63 | 14 |
| 3 m east | .69 | .62 | .68 | .66 | 32 |
| | .67 | .60 | .66 | .64 | Average |
| 6 m west | .74 | .67 | .70 | .70 | 14 |
| 6 m east | .72 | .65 | .72 | .70 | 32 |
| | .73 | .66 | .71 | .70 | Average |

6. **Average value of Test Runs Result:**

| Pre Test | .65 | Post Test | .63 |
|---|---|---|---|

7. **Reference**

| Test equipment | Test tyre Type pressure (kpa) | | Test speed (km/h) | Test water depth | Design objective for new surface | Maintenance planning levels | Minimum friction level |
|---|---|---|---|---|---|---|---|
| (1) | (2) | | (3) | (4) | (5) | (6) | (7) |
| Surface Friction Tester Vehicle | B | 210 | 65 | 1.0 | 0.82 | 0.60 | 0.50 |
| | **B** | **210** | **95** | **1.0** | **0.74** | **0.47** | **0.34** |

Friction testing done

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### 1.10.5 The Reported Runway Condition and Associated Reports by ATC or Pilot on 03 Jun 2020

| S. No. | Time with CTC with Tower | Wind Direction & Velocity Reported by ATC | RWY Condition Passed by ATC | Weather Reported by Pilot | RWY Condition Reported by Pilot | RWY |
|---|---|---|---|---|---|---|
| 1. | 0345 | 040/12 | WET | No Report | Poor | 14 |
| 2. | 0412 | 040/15 | WET | No Report | Good | 27 |
| 3. | 0437 | 030/13 | WET | No Report | No Report | 14 |
| 4. | 0449 | 040/18 | WET | No Report | No Report | 14 |
| 5. | 0541 | 030/11 | WET | No Report | No Report | 14 |
| 6. | 0748 | 020/13 G3 | WET | No Report | Medium | 14 |

### 1.10.6 Civil Aviation Regulations

DGCA Civil Aviation Requirements, Section - 4, Aerodrome Standards & Licensing, Series 'B', Part I, Issue II dated 26$^{th}$ August 2015 states that (Extract of relevant portion):

***Water on a runway***

2.9.5 Whenever water is present on a runway, a description of the runway surface conditions shall be made available using the following terms:
DAMP — the surface shows a change of colour due to moisture.
WET — the surface is soaked but there is no standing water.
STANDING WATER — for aeroplane performance purposes, a runway where more than 25 per cent of the runway surface area (whether in isolated areas or not) within the required length and width being used is covered by water more than 3 mm deep.
2.9.6 Information that a runway or portion thereof may be slippery when wet shall be made available.
*Note* — The determination of a runway or portion thereof may be slippery when wet is not based solely on the friction measurement obtained using a continuous friction measuring device.
2.9.7 Notification shall be given to aerodrome users when the friction level of a paved runway or portion thereof is less than as specified.
3.1.23 A paved runway shall be so constructed or resurfaced as to provide surface friction characteristics at or above the minimum friction level set by the DGCA.
3.1.24 The surface of a paved runway should be evaluated when constructed or resurfaced to determine that the surface friction characteristics achieve the design objectives.

3.1.25 Measurements of the surface friction characteristics of a new or resurfaced paved runway shall be made with a continuous friction measuring device using self- wetting features.

10.2.3 A paved runway shall be maintained in a condition so as to provide surface friction characteristics at or above the minimum friction level.

10.2.4 Runway surface friction characteristics for maintenance purposes shall be periodically measured with a continuous friction measuring device using self-wetting features and documented. The frequency of these measurements shall be sufficient to determine the trend of the surface friction characteristics of the runway.

10.2.5 Corrective maintenance action shall be considered when the friction characteristics for either the entire runway or a portion thereof are below a specified maintenance planning level.

Note — A portion of runway in the order of 100 m long may be considered significant for maintenance or reporting action.

7. Determination of surface friction characteristics for construction and maintenance purposes.

7.1 The surface friction characteristics of a paved runway should be:

(a) Assessed to verify the surface friction characteristics of new or resurfaced paved runways; and

(b) Assessed periodically in order to determine the slipperiness of paved runways.

7.2 The condition of a runway pavement is generally assessed under dry conditions using a self-wetting continuous friction measuring device. Evaluation tests of runway surface friction characteristics are made on clean surfaces of the runway when first constructed or after resurfacing.

7.3 Friction tests of existing surface conditions are taken periodically in order to avoid falling below the minimum friction level specified by the DGCA. When the friction of any portion of a runway is found to be below this value, then such information is promulgated in a NOTAM specifying which portion of the runway is below the minimum friction level and its location on the runway. A corrective maintenance action must be initiated without delay. Friction measurements are taken at time intervals that will ensure the identification of runways in need of maintenance or of special surface treatment before their condition becomes serious. The time intervals and mean frequency of measurements depend on factors such as: aircraft type and frequency of usage, climatic conditions, pavement type, and pavement service and maintenance requirements.

7.4 Friction measurements of existing, new or resurfaced runways are made with a continuous friction measuring device provided with a smooth tread tire. The device should use self-wetting features to allow measurements of the surface friction characteristics to be made at a water depth of 1 mm.

7.5 When it is suspected that the surface friction characteristics of a runway may be reduced because of poor drainage, owing to inadequate slopes or depressions, then an additional measurement is made, but this time under natural conditions representative of a local rain. This measurement differs from the previous one in that water depths in the poorly cleared areas are normally greater in a local rain condition. The measurement results are thus more apt to identify problem areas having low friction values that could induce aquaplaning than the previous test. If circumstances do not permit measurements to be conducted during natural conditions representative of a rain, then this condition may be simulated.

7.6 When conducting friction tests using a self-wetting continuous friction measuring device, it is important to note that, unlike compacted snow and ice conditions, in which there is very limited variation of the friction coefficient with speed, a wet runway produces a drop in friction with an increase in speed. However, as the speed increases, the rate at which the friction is reduced becomes less. Among the factors affecting the friction coefficient between the tire and the runway surface, texture is particularly important. If the runway has a good macro-texture allowing the water to escape beneath the tire, then the friction value will be less affected by speed. Conversely, a low macro- texture surface will produce a larger drop in friction with increase in speed.

7.7 A minimum friction level is a value below which corrective maintenance action should be taken. As criteria for surface friction characteristics of new or resurfaced runway surfaces and its maintenance planning, the DGCA has established a maintenance planning level below which appropriate corrective maintenance action should be initiated to improve the friction.

7.8 Table below provides guidance on establishing the design objective for new runway surfaces and maintenance planning and minimum friction levels for runway surfaces.

Runway Surface condition levels

| Test equipment | Test tire Type | Test tire Pressure (kPa) | Test speed (km/h) | Test water depth (mm) | Design objective for new surface | Maintenance planning level | Minimum friction level |
|---|---|---|---|---|---|---|---|
| (1) | (2) | | (3) | (4) | (5) | (6) | (7) |
| Mu-meter Trailer | A | 70 | 65 | 1.0 | 0.72 | 0.52 | 0.42 |
| | A | 70 | 95 | 1.0 | 0.66 | 0.38 | 0.26 |
| Skiddometer Trailer | B | 210 | 65 | 1.0 | 0.82 | 0.60 | 0.50 |
| | B | 210 | 95 | 1.0 | 0.74 | 0.47 | 0.34 |
| Surface Friction Tester Vehicle | B | 210 | 65 | 1.0 | 0.82 | 0.60 | 0.50 |
| | B | 210 | 95 | 1.0 | 0.74 | 0.47 | 0.34 |
| Runway Friction Tester Vehicle | B | 210 | 65 | 1.0 | 0.82 | 0.60 | 0.50 |
| | B | 210 | 95 | 1.0 | 0.74 | 0.54 | 0.41 |
| TATRA Friction Tester Vehicle | B | 210 | 65 | 1.0 | 0.76 | 0.57 | 0.48 |
| | B | 210 | 95 | 1.0 | 0.67 | 0.52 | 0.42 |
| RUNAR Trailer | B | 210 | 65 | 1.0 | 0.69 | 0.52 | 0.45 |
| | B | 210 | 95 | 1.0 | 0.63 | 0.42 | 0.32 |
| GRIPTESTER Trailer | C | 140 | 65 | 1.0 | 0.74 | 0.53 | 0.43 |
| | C | 140 | 95 | 1.0 | 0.64 | 0.36 | 0.24 |

All the above requirements were fulfilled for Mumbai Airport and friction tests were carried out as per the requirements.

DGCA has revised the above CAR on 19 July 2021 (in-line with ICAO Doc 9981) effective from 04 Nov 2021.

### 1.10.7 SAGA (Surface Awareness Guidance at Airport) Report

SAGA Plots were obtained from the Aerodrome Operator.

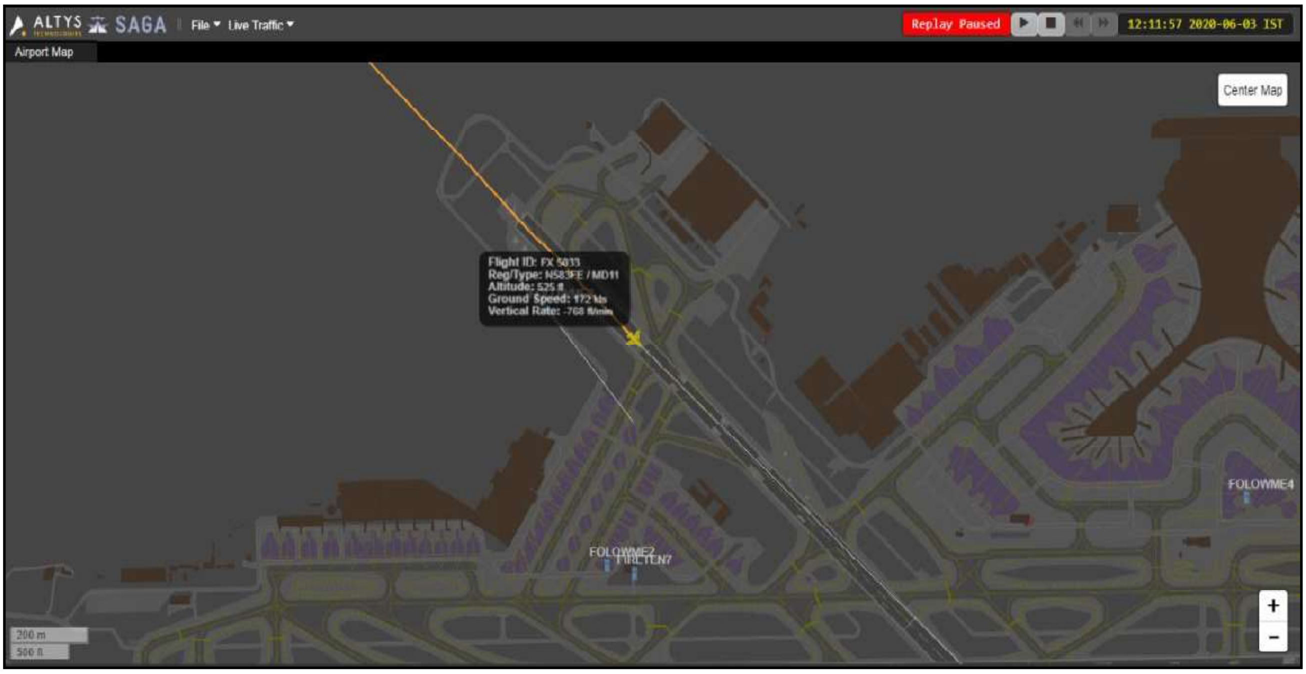



**Fig - 10**: The above SAGA Radar image shows the Aircraft crossing the runway 14 threshold (ALT 525′/GS172 Kts/Vert Spd -768 fpm).

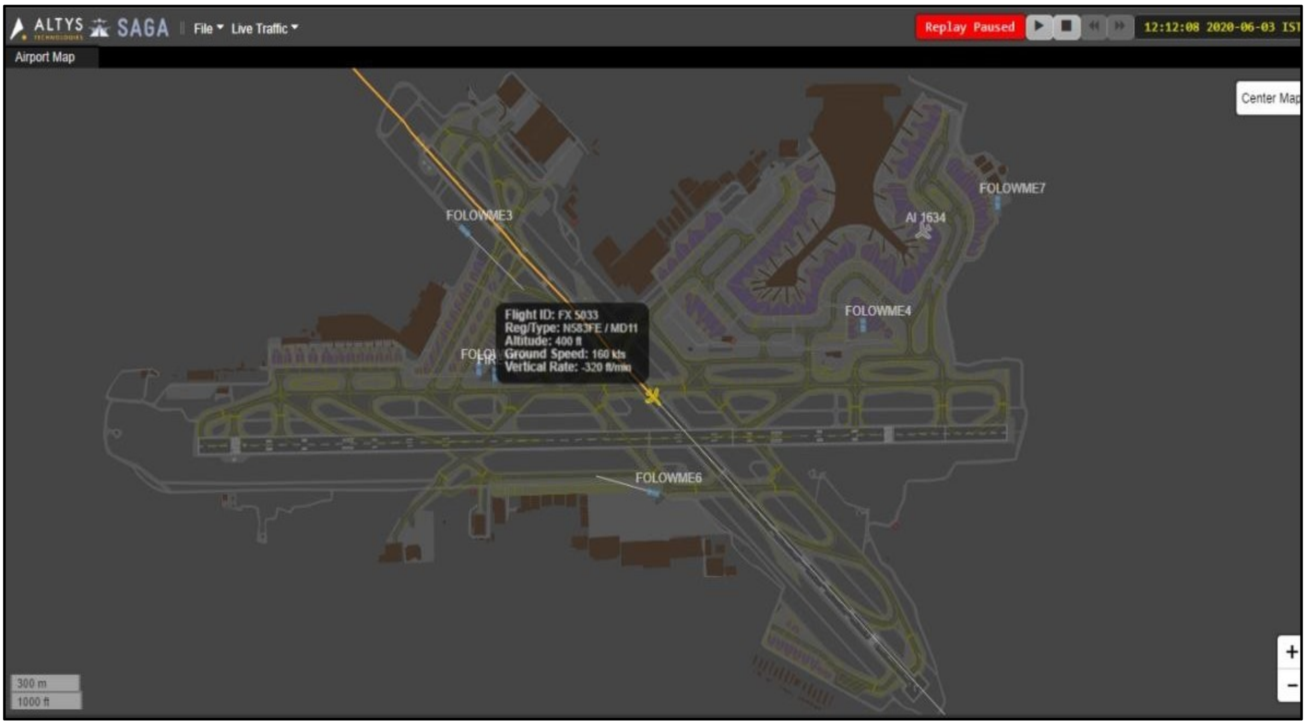



**Fig-11**: The above SAGA Radar image shows the Aircraft approaching runway intersection (ALT 400' / GS 160 Kts / Vertical Speed -320 fpm

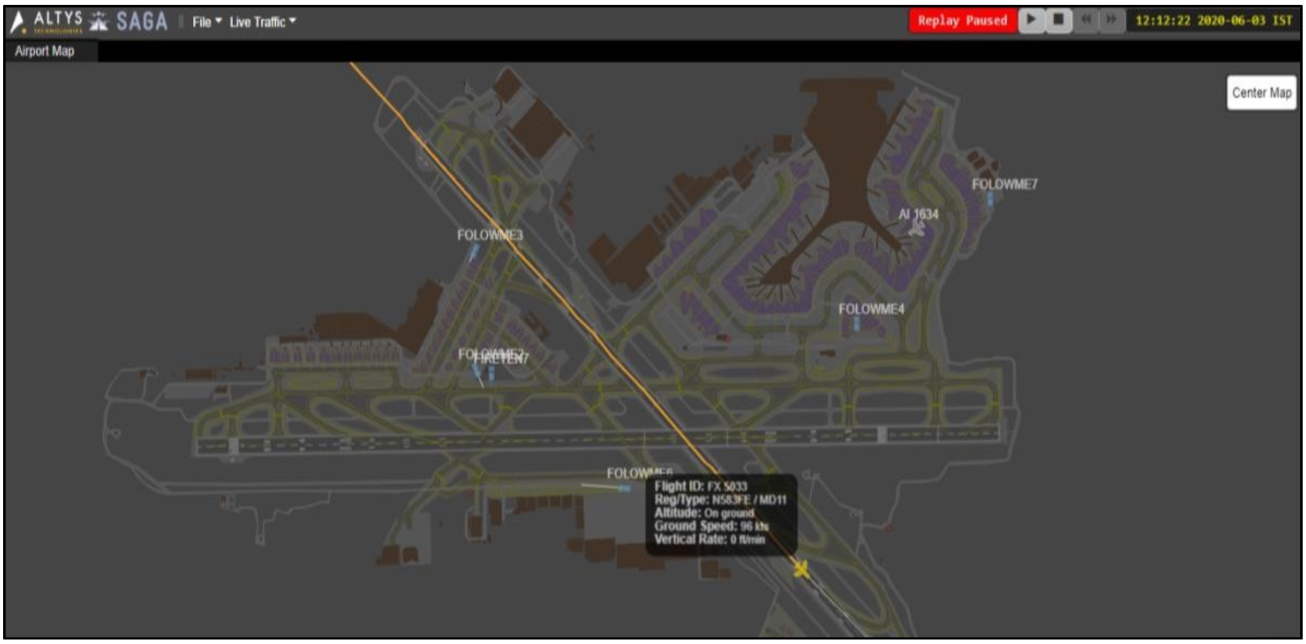



**Fig-12**: The above SAGA Radar image shows the position of aircraft after crossing taxiway E4. ALT 0' / GS 96 Kts / Vertical Speed - 0 fpm

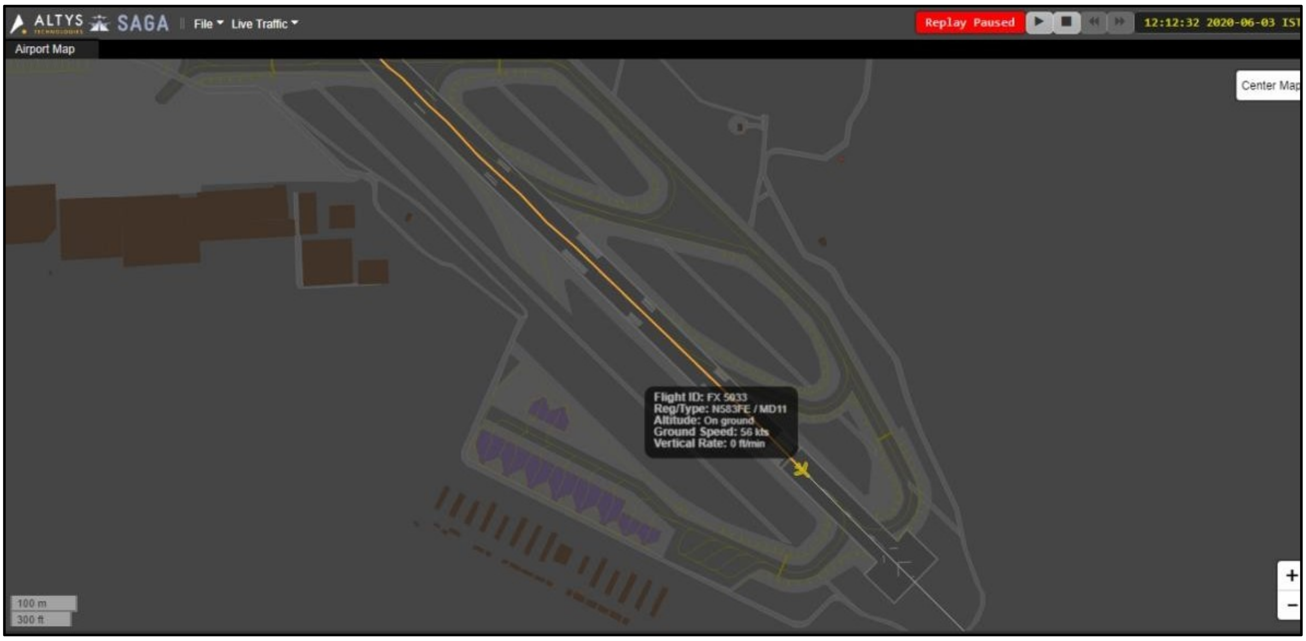



**Fig-13**: The above SAGA Radar image shows the position of the aircraft crossing the Runway 32 Threshold (ALT 0’ / GS 56 Kts / Vertical Speed 0 fpm).

### 1.10.8 Aerodrome CCTV Location which Captures the Aircraft Touchdown


**Fig-14** : The Google earth plot (Screenshot) showing the location of the aircraft Main Landing Gear touchdown (Reference CCTV Image). The nose wheel has not yet touched down and the spoilers have yet to deploy

### 1.10.9 Screen Shots from CCTV Recordings

There are 2 CCTV camera arrays that captured the video of the landing aircraft. The CCTV video was used to establish the actual touchdown point of the aircraft.

**Fig-15:** (CCTV 1 Image 1) Shows the entire range of the CCTV based on the location.


**Fig-16** : (CCTV 1 Image 2) Shows the aircraft approaching over the landing Threshold for Runway 14. The Aircraft appears to be on the vertical profile.

**Fig-17:** (CCTV 1 Image 3): Shows the aircraft has not yet touched down on the main gear. This is the approximate location of the touchdown markings.

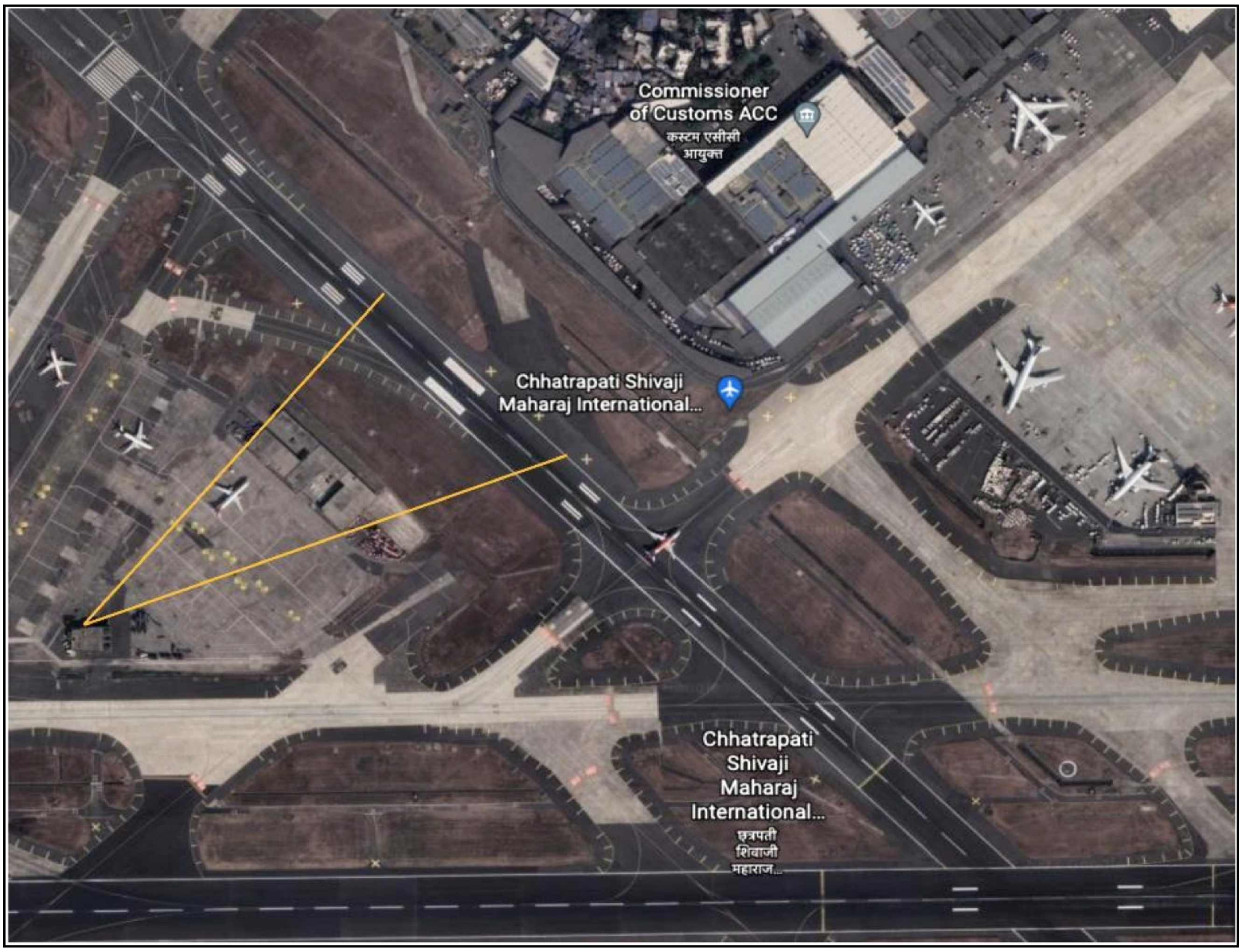



**Fig-18**: The Google earth plot (Screenshot) shows the area that is obstructed for runway surface view due to building structures


**Fig-19**: (CCTV 1 Image 4) shows the aircraft left main landing gear rear wheels contacting the runway surface. The center and right main landing gear are still in the air.


**Fig-20**: (CCTV 1 Image 5) Shows All main landing gear having contacted the runway surface. The nose wheel has still not contacted the runway. There is no spoiler deployment over the wings at this point.

**Fig-21**: (CCTV 2 Image 1) The CCTV on the south eastern end of the runway shows the aircraft number 1 engine having a small flame in the exhaust section.


**Fig-22**: The Google earth plot (Screenshot) shows the aircraft location when the 1st flame is visible

**Fig-23**: (CCTV 2 Image 2) shows a second and more prominent flame from the number 1 engine.

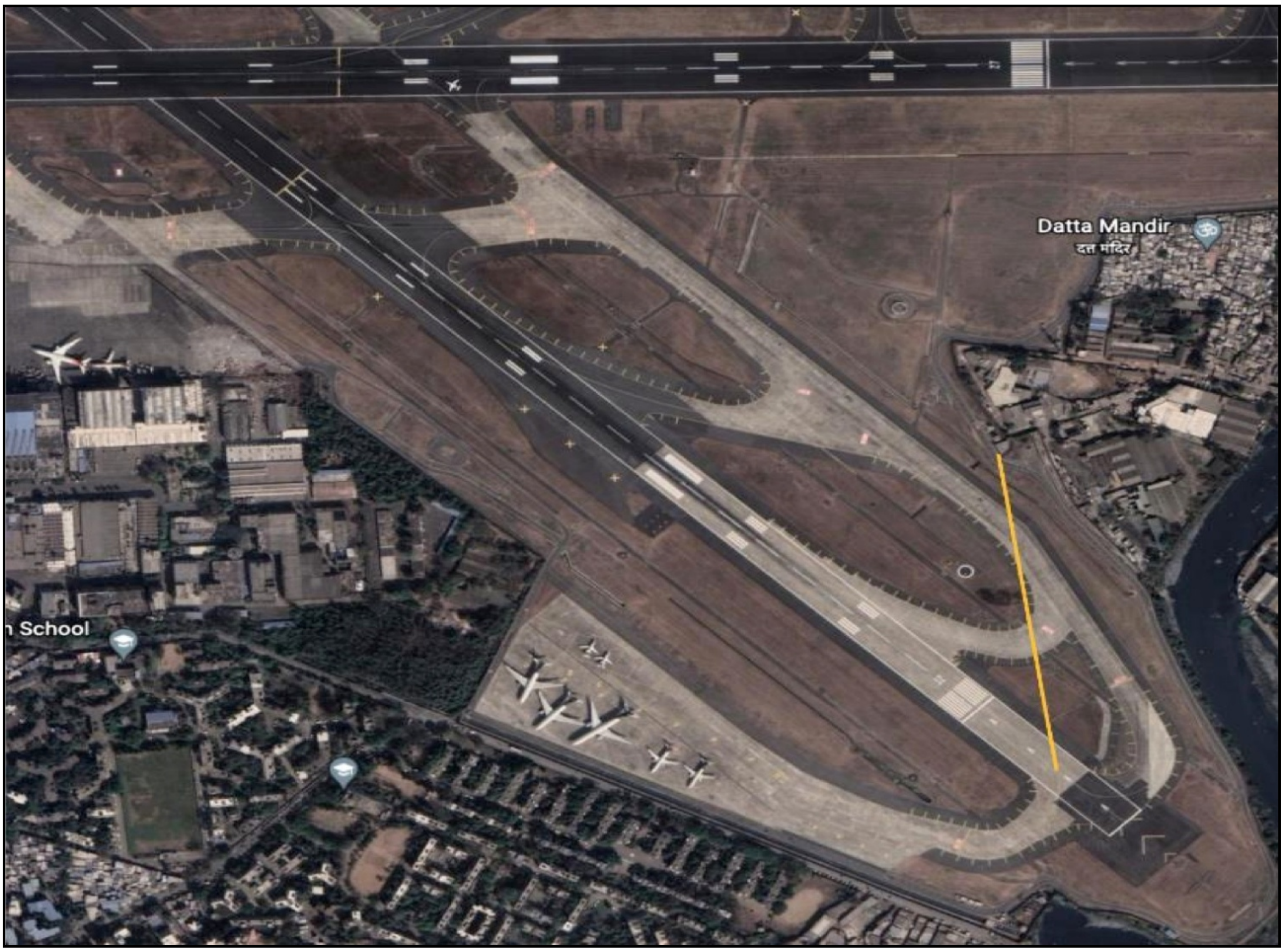



**Fig-24**: The Google earth plot (Screenshot) image of the aircraft when the number 1 engine flame is visible for the second time.

**Fig-25**: (CCTV 2 Image 3): Aircraft stopped facing 26$^{0}$ left of centerline

**Fig-26**: (CCTV 2 Image 4): Aircraft position at final stop, perpendicular to the runway after attempting a right turn to vacate the runway. This was the final position of the aircraft.

**Fig-27**: (CCTV 2 Image 5): Fire and Rescue services dispatched to the aircraft

### 1.10.10 Aerodrome Radar Plot

The figure 28 & 29 below has been obtained from the aerodrome radar plot and updated with the aircraft dimensions while the aircraft is stationary. The image shows the aircraft nose wheel having crossed the declared runway surface while remaining on the paved surface designed to carry the aircraft weight.

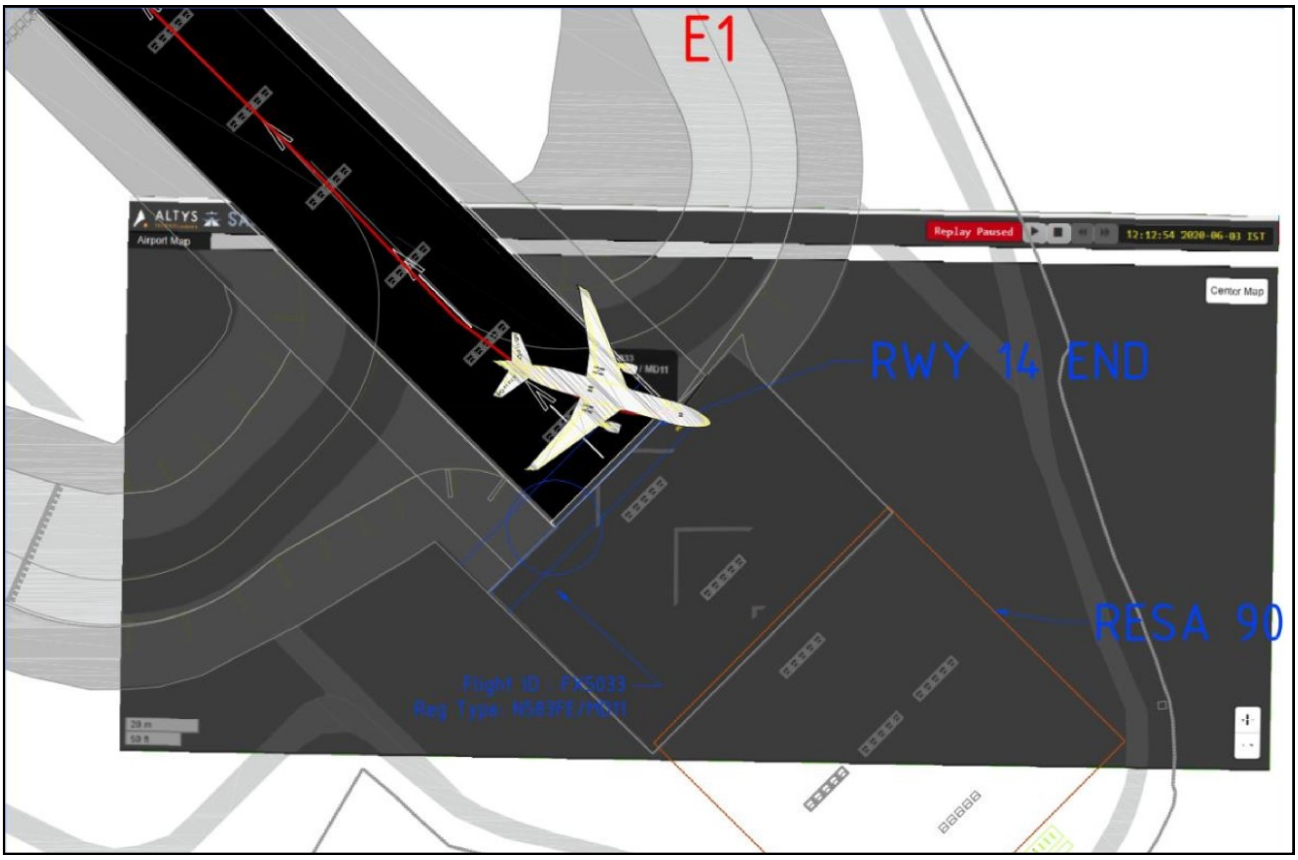



**Fig-28**: PLAN VIEW of the Aircraft once it comes to a stop after the landing.

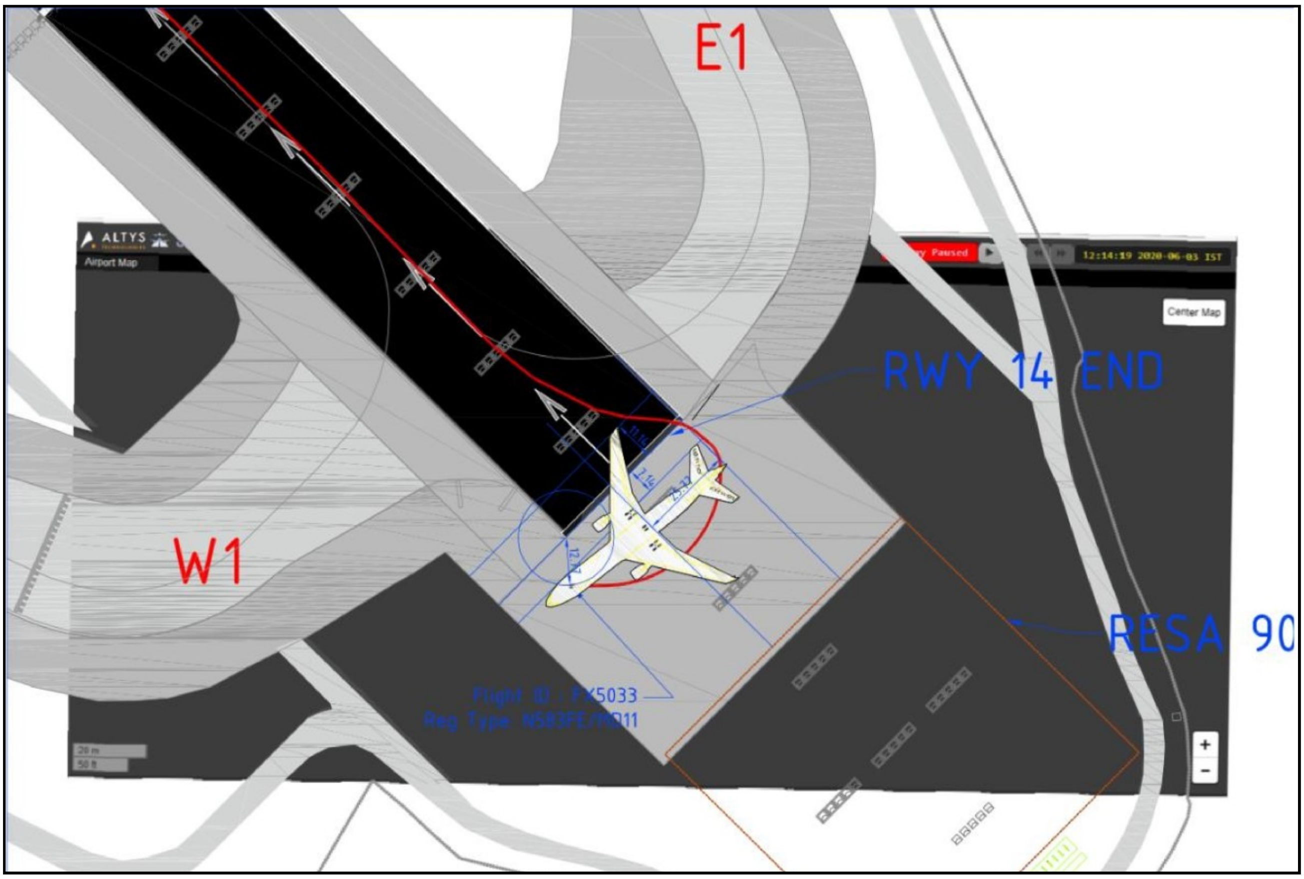



**Fig-29**: PLAN VIEW of the Aircraft after the crew attempt to steer the aircraft.

## 1.11 Flight Recorders

**1.11.1 CVR** was installed on the aircraft. The CVR recording was however not secured (through circuit breaker pull) after the incident. The relevant portion of the CVR was overwritten.

**1.11.2 FDR** was installed on the aircraft but was under MEL for limited parameter capture

FLIGHT RECORDER READOUT FOUND THAT FDR RECORDING; PARAMETERS NOT REQUIRED BY FAR MISSING

MEL 02 Jun 20, 15:35 BLR

RELEASED FOR SERVICE PER MEL : 31-31-01-02 CATEGORY : A EXPIRATION : 13 Sep20

"MEL 31-31-01-02: FDR PARAMETER INOP."

Non-mandatory parameters:

DME #2 inaccurate.

**MD-11 Minimum Equipment List**

ATA - 31 INDICATING AND RECORDING

| ITEM | | FAA CATEGORIES | NORMAL COMPLEMENT | MINIMUM REQUIRED FOR TAKEOFF | REMARKS OR EXCEPTIONS |
|---|---|---|---|---|---|
| 31-31-01-02 | Flight Data Recorder (FDR) System — **DFDR Recording Parameters not required by FAR** | A | - | 0 | **(O)** **(M)** May be inoperative provided repairs are made prior to the completion of the next heavy maintenance check. |

The next heavy maintenance check was the "B" check.

***Many of the parameters including brake parameters and autobrake selection were not recorded.***

### 1.11.3 OEM FDR Report

The FDR was submitted to NTSB in order to obtain the handling report. In addition specific queries based on phase of flight were requested.

Boeing Responses to Requests from the AAIB:

***Handling Quality Report***

OEM carried out FDR simulation based on various assumptions as most of the relevant parameters were not available (Refer Section 1.16).

***Aircraft speed profile from Top of Descent (TOD) to 10,000′***

The aircraft speed profile during the descent from cruise to 10,000′ appeared ordinary with no anomalies noted. Speed brakes were deployed at various times throughout the descent, which is a normal operation.

***Aircraft speed profile from 10,000′ to 2000′***

The aircraft speed profile during the initial approach phase, from 10,000′ down to 2,000′ appeared ordinary with no anomalies noted. Speeds remained in the expected operational ranges.

***Aircraft speed profile below 2000′ to touchdown***

The aircraft speed profile during the final approach phase, from 2,000′ down to touchdown appeared ordinary with no anomalies noted. Speeds remained in the expected operational ranges.

***Wind component graph below 2000′ to touch down***

The recorded winds from 2000′ until touchdown were not valid in sideslip or on the ground. As the airplane begins aligning with runway heading 135 at approximately 200 ft Radio Altitude, recorded wind parameters indicate 12 kt winds from direction 023 degrees resulting in a 11 kt crosswind component and 4 kt tailwind component. This generally agrees with the reported winds of 12 knots gusting to 22 knots from heading 030 degrees that would result in a tailwind component of approximately 3 to 6 knots. (For details-refer Para 1.16).

***Wind component graph from touchdown to stop***

The recorded winds are not valid when the airplane is on the ground. Though a rough estimate of the winds throughout the landing roll would have been carried out, but the interaction of the landing gear and runway preclude any detailed wind determination on ground.

***Time (elapsed) between touchdown (1st Sensor pickup) and selection of reverse thrust***

The throttle positions are not recorded, so the selection of reverse thrust to answer this question is based on the first recorded sample where any thrust reverser is not completely stowed. The touchdown time was determined by the recorded vertical and longitudinal accelerations.

The time difference between these events is 2.52 seconds, so reverse thrust was selected approximately 2 seconds after touchdown, accounting for recording sample rate and reverser actuation time.

***Time (elapsed) between selections of reverse thrust and maximum reverse selected***

The reverse thrust parameters are shown above. Throttle positions are not recorded, but it can be seen that maximum reverse N1 reached approximately 6.4 seconds after the reversers were deployed.

***Engine abnormal parameter readings, if any, vis-à-vis thrust setting, thrust command, ground speed, Heading variation w.r.t. runway.***

No anomalies were noted in any engine parameter readings. Normal procedure is to stow the thrust reversers at 80 knots. In this case, the reverser began to stow, but the reversers were redeployed and maximum reverse thrust again applied. Ground speed analysis is continuing. The airplane maintained runway heading with normal variations until the groundspeed reach about 50 knots, when a left turn was initiated.

***Brake application, time (seconds) elapsed between touchdown & application of brake force (psi).***

Braking parameters were not recorded.

***If the auto brake was selected.***

The auto brake setting was not recorded.

The OEM carried out a MD-11 desktop simulation to match the recorded flight data as closely as possible to both validate the recorded data and to produce estimates for parameters that were not recorded. A specific emphasis was to be placed on aircraft braking and estimated runway friction throughout the landing roll.

## 1.12 Wreckage and Impact Information

NIL

## 1.13 Medical and Pathological Information

The flight crew were operating the aircraft under FAA regulations. However, the crew was not subjected to any medical examination after the incident.

## 1.14 Fire

There was no Fire.

## 1.15 Survival Aspects

The incident was survivable.

## 1.16 Tests and Research

OEM, in view of many FDR parameters not available, carried out desk top simulation using dataframe documentation of another MD 11 aircraft. The report is as follows:

### 1.16.1 OEM Desktop Simulation

The FDR data was provided in raw format and required conversion to engineering units according to the dataframe in use on the event airplane. However, as updated dataframe documentation for the event airplane was not provided, documentation for a similar FedEx MD-11 airplane was used as a reference.

Selected FDR parameters are shown in Figures 1 through 5.

Figure 1 describes the engine and autopilot parameters,

Figures 2 and 3 describe the longitudinal parameters, and

Figures 4 and 5 describe the lateral-directional parameters.

The “Relative Time [Seconds]” title along the x-axis of these figures represents the elapsed time from an arbitrary point initialized as the start of the segment of flight being viewed.

In addition to an evaluation of the recorded parameters, a kinematic consistency analysis was conducted utilizing a desktop simulation tool known as Generic Simulation Code (GSC) and a module for data consistency and wind estimation known as CONSIST. The CONSIST module computes inertial results using an integration of FDR recorded Euler angles and user-supplied FDR accelerometer biases identified through a detailed FDR time-history matching process with GSC. The FDR recorded airspeed data and the integrated inertial data, along with the full aircraft aerodynamic model, are then used to estimate the wind profile.

The FDR data show the airplane established on a stabilized approach configured for a 50/EXT landing, landing gear down and locked, spoilers armed, glideslope and localizer deviations nominal with autopilot and auto throttles engaged in an instrument landing system (ILS) approach to BOM Runway 14. At 1000 feet above ground level (AGL), the recorded gross weight and center of gravity (CG) were approximately 448,000 pounds and 28.8% of the Mean Aerodynamic Chord (MAC) respectively. The selected airspeed for approach was

162 knots. For an MD-11 airplane configured for a 50/EXT landing at 448,000 pounds landing weight, the MD-11 Flight Crew Operating Manual (FCOM) references a Vref speed of 151 knots by interpolation. Thus, the 162 knots selected airspeed represents an approach speed of Vref+11 knots. Given the runway true heading of 134.5 degrees, the airplane would have been experiencing a tailwind component of 5 knots and a crosswind component of 11 knots from the left based on the reported winds. The airplane was crabbed to the left, in the direction of the crosswind component, at a drift angle of approximately 8 degrees. Perturbations in key parameters, such as computed airspeed, vane angle of attack, and the acceleration parameters, along with increased control deflections to maintain the desired attitude and small adjustments to thrust to maintain the desired speed, are indicative of a turbulent atmosphere.

Throughout the approach, the selected airspeed of 162 knots was maintained with computed airspeed deviations between +/- 10 knots. During this time, ground speed was approximately 172 knots and the calculated descent rate (negative vertical speed) was approximately 900 feet per minute (fpm). Speeds were within the expected operational range and no limits were exceeded.

Autopilot was disengaged at approximately 500 feet radio altitude with autothrottle remaining engaged. The airplane began trending high on glideslope upon disengaging the autopilot, but this was corrected as the airplane came closer to touchdown. As the airplane descended below 300 feet radio altitude, a de-crab maneuver was performed, aligning the airplane magnetic heading to approximately 135 degrees. Shortly after, as the airplane approached 50 feet radio altitude, the airplane pitch attitude was increased to approximately 4 degrees, arresting the sink rate (negative vertical speed about the CG) to about 5 feet per second at touchdown.

Touchdown likely occurred at approximately 132 seconds, about 1,540 feet past the runway threshold of runway 14 as indicated by a slight decrease in longitudinal acceleration and an increase in normal load factor. At touchdown, normal load factor increased to approximately 1.3 g's, pitch attitude was approximately 5 degrees, bank angle was near wings-level, computed airspeed was approximately 150 knots, and ground speed was approximately 165 knots. The calculated tailwind component at touchdown, derived from the calculated wind speed was approximately 15 knots with a left crosswind component of approximately 17 knots (Figure 5).

FDR data show that ground spoilers were deployed to full deflection upon touchdown and remained deployed until the airplane came to a complete stop. Similarly, all three thrust reversers deployed as expected after touchdown. After approximately 15 seconds, thrust reversers began transitioning to Stow when they were once again deployed until the airplane came to a complete stop.

Calculation of Winds

Winds were calculated using a multi-step kinematic analysis known as the "CONSIST and proof-of- match" process that relies on the Euler angles (pitch attitude, bank angle, and heading angle), and their rates. The FDR does not record the Euler angle rates. The Euler angles are sampled at different times and with relatively low sampling rates. To increase the sampling rates and match the sampling times of the signals, the recorded traces were processed, using a linear or spline interpolation as appropriate for each parameter, yielding a data set with consistent timing and adequate sample rate for further analysis. The resulting smooth rates are needed to allow the simulation tuners to work properly when applying the pilot algorithms later on in the process. The winds are derived using the recorded inertial accelerations with instrumentation biases removed along with now-smooth Euler angles, Euler angle rates, and the aerodynamic characteristics of the airplane. The wind profile was smoothed during the observed flare maneuver. Since the calculated winds are invalid after the airplane is on the ground due to noise in the signals from interaction with the ground and uncertainties in the forces being applied to the airplane by the landing gear, the on-ground portion of the wind profile for this analysis is an estimation based upon an iterative matching of airspeed and inertial parameters. During the ground roll, the crosswind component was set to zero and the tailwind adjusted for best match of the airspeed and groundspeed parameters.

Below 1000 feet radio altitude, calculated winds correlated well with recorded winds while exhibiting more dynamic variations (Figure 6). During this segment, the airplane experienced an average tailwind of 10 knots and a left crosswind component of approximately 20 knots that would gradually shift to a greater tailwind component of 15 knots by touchdown.

Proof of Match

In this investigation, the brake position, brake pressure, and related ground parameters were not available within the FDR data set. The missing parameters were simulated by leveraging the airplane and aerodynamic model by way of an iterative inertial and kinematic matching process previously referred to as the proof-of-match process. An initial step in the proof-of-match process is iteration through the initial conditions of the airplane in a relatively steady point in the air using the FDR recorded control inputs and wind profile until the energy on the simulation is in balance with the energy recorded on the aircraft. Three variables often used to determine the energy balance are airspeed, radio altitude, and pitch attitude. Math tuners in the GSC simulation were used to enhance the recorded pilot controls when matching the computed Euler angles. The pitch attitude is left to be computed by the simulation and is not driven during the proof of match, providing a viewing window to the airplane body-axis during the process. When the airspeed and radio altitude match between the simulation and recorded traces, the energy of the events are determined to be in balance. Once the in-air portion of the analysis was completed, the math tuners were turned off and the simulation proceeded using the recorded control inputs.

Ground Analysis

The airplane crossed BOM Runway 14 threshold at a radio altitude of approximately 50 feet and calibrated airspeed of approximately 158 knots with an approximate tailwind component of 15 knots. At time 132 seconds, main gear touchdown occurred 1,540 feet past runway threshold at a calibrated airspeed of approximately 150 knots. Deployment of ground spoilers immediately followed as the airplane de-rotated over the span of approximately four seconds. During this time, longitudinal deceleration increased to an average value of 0.2 g's. Two seconds following nose gear compression, thrust reversers were deployed to full reverse thrust as characterized by an increase in engine N1 to 100%.

On the ground, the simulation engine model was tuned to match the reverse thrust profile depicted in the recorded N1 engine parameters. Maintaining the energy balance between the simulation model and the recorded airplane parameters, a series of tests were performed to identify the runway friction coefficient profile as well as the estimated braking profile as shown in Figures 7 and 8.

The airplane-braking coefficient ($\mu_{airplane}$) was calculated for the landing and is shown versus distance traveled in Figure 8. The "Distance" parameter is the distance along centerline from the runway 14 threshold. Airplane braking coefficient ($\mu_{airplane}$) is a calculated term defined as the ratio of the deceleration force from the wheel brakes relative to the normal force acting on the wheels. The deceleration force from the wheel brakes is calculated from the total airplane deceleration minus aerodynamic drag and thrust components, and the normal force acting on the main gear wheels is essentially weight minus lift. The airplane-braking coefficient is an all-inclusive term that incorporates effects due to the runway surface, contaminants, and airplane braking system (e.g., antiskid efficiency, brake wear, tyre condition, etc.). Therefore, the $\mu_{airplane}$ is not equivalent to the tyre-to-ground friction coefficient ($\mu_{Runway}$) that would be measured by an airport ground vehicle.

The $\mu_{airplane}$ represents the braking capability of the airplane and only represents the runway characteristics when the brake/antiskid system is friction-limited. The brake/antiskid system is friction-limited when the commanded brake pressure is greater than or equal to the brake pressure governed by the antiskid valve. The antiskid system adapts to the runway conditions by sensing an impending skid condition and adjusting the brake pressure to each individual wheel for maximum braking. When not friction-limited, the airplane-braking coefficient represents the level of braking applied.

The $\mu_{airplane}$ calculation method assumes that 1) the recorded airplane longitudinal acceleration data are valid, 2) any aerodynamic, propulsion, flight controls, or gear modeling errors are small, 3) other external forces, including runway slope and drag produced by contaminants are negligible, and 4) there were no braking system anomalies that would have affected the braking action.

Since braking level parameters were not recorded and runway friction was unknown, it is not possible to separate the two with certainty. Therefore, assumptions were made regarding braking level, and the braking coefficient (which includes the runway friction) was derived based on those assumptions. The landing ground roll is characterized in phases. First, from time 132 to 140, little or no braking is observed. Since MED auto- brakes target a deceleration level, not a target braking level, this section is consistent with MED auto-brake use. The deceleration came primarily due to reverse thrust, with the $\mu_{airplane}$ not a significant contributor in this phase. The second phase, from time
140 to 152 needed an increased braking level. After time 152, since the thrust reversers had been redeployed, it was assumed that maximum braking had been applied and it is in this phase that variations in $\mu_{airplane}$ become apparent.

The airplane braking coefficient at 5,900 feet beyond the threshold (~2,200 feet runway distance remaining) is estimated to be a value of approximately 0.22 which is characteristic of good braking action on damp/wet surface conditions. The braking coefficient varies along the runway ranging from values as high as 0.4 toward the end of the runway to values as low as 0.15 as shown in Figures 7 and 8. An airplane braking coefficient of 0.15 is characteristic of medium braking action on wet surface conditions.

At approximate time 155 seconds, 6,200 feet beyond the threshold (~1,900 feet runway distance remaining) and a computed airspeed of approximately 70 knots, the thrust reversers began transitioning to stow. In this segment of the landing rollout, the estimated $\mu_{airplane}$ fell from 0.22 to approximately 0.17. Three seconds later, a manual re-deployment back to full reverse thrust was initiated. This activity is characterized on Figures 1, 7, and 8. At approximately this time, manual braking is assumed to have been increased to max braking until a complete stop was achieved.

The total stopping distance from touchdown to a complete stop was approximately 6,567 feet. When the groundspeed reached 34 knots, an approximate 26 degree left turn is observed in the recorded flight data, leaving the airplane pointed approximately 30 degrees to the left of centerline. The airplane came to a complete stop in the corner of runway 14, near but not crossing the end line.

About 45 seconds later (not shown), the airplane made a right turn, crossing the end line, to a heading of about 232 degrees (perpendicular to the runway) and came to a stop on the blast pad with the right main landing gear measured to be approximately 7 meters (~23 feet) beyond the end of the runway. The engines were subsequently shut down.

Performance Analysis

A performance analysis was conducted to calculate the required landing rollout distances under different hypothetical scenarios for comparison. A list of assumptions was made to approximately recreate the landing scenario at BOM Runway 14 based upon the reported information regarding the runway conditions and airplane configuration. The assumptions are listed on Table 1.

Table 1 Performance Analysis Configuration Summary

| Flaps | Weight (lb) | Temp (degrees Celsius) | Winds (knots) | Runway Elevation at Touchdown (feet) | Runway Slope (%) |
|---|---|---|---|---|---|
| 50 | 448,000 | 27 | -5* -15** | 40 | -0.15 |

* Constant tailwind component of the reported winds.

** Constant tailwind component of the calculated winds.

For the purpose of this landing performance analysis, landing distances were calculated based upon AC 25-32 guidelines established by the Takeoff and Landing Performance Assessment Aviation Rulemaking Committee (TALPA ARC) guidance. The Runway Condition Codes (RCC) used to simulate and bracket the best case and worst case scenarios were RCC 5 and RCC 3 respectively.

The two deceleration profiles studied as a part of this analysis are:

(1) Normal reverse thrust procedure (stow by 60 knots) with max manual anti- skid braking applied.

(2) Reverse thrust to complete stop with max manual anti-skid braking applied.

The data for deceleration profile 1 is taken from the FCOM and would have been available to the pilots before landing. Deceleration profile 2 data, which includes reverse thrust below 60 knots, is not published and was calculated by Boeing for this investigation.

Boeing does not publish landing distances for the MD-11 with autobrake levels less than maximum.

***Table 2.*** Performance Analysis Results Summary

| Constant Tailwind Component (knots) | Reported Braking* | Deceleration Profile** | Landing Distance (feet) | Air Run Threshold to Touchdown (feet) | Stopping Distance from Touchdown (feet |
|---|---|---|---|---|---|
| -5 | Good | 1 | 5950 | 1876 | 4953 |
| -5 | Good | 2 | 5881 | 1876 | 4005 |
| -5 | Medium | 1 | 7348 | 1876 | 5472 |
| -5 | Medium | 2 | 6836 | 1876 | 4960 |
| -15 | Good | 1 | 7001 | 2048 | 4953 |
| -15 | Good | 2 | 6870 | 2048 | 4822 |
| -15 | Medium | 1 | 8856 | 2048 | **6608** |
| -15 | Medium | 2 | 7922 | 2048 | 5874 |

* Based upon TALPA ARC AC 25-32 Runway Condition Codes: Good-RCC 5 Medium - RCC 3

** Hypothetical scenarios employing the following deceleration devices: 1 – Max

Reverse thrust to 80 KIAS, Reverse Idle to 60 KIAS, Forward Idle to stop, Max Manual Anti-skid braking. 2 – Max Reverse thrust to stop, Max Manual Anti-skid braking.

**Conclusion**

Analysis of the FDR data indicates that the approach to Runway 14 in turbulent atmosphere was stable. The airplane touched down within the touchdown zone at an acceptable closure rate of 5 fps, approximately 1,540 feet beyond the runway threshold at VREF. Following touchdown, ground spoilers and thrust reversers were deployed in full reverse thrust. However, the lack of FDR recorded braking parameters required significant assumptions to be made in the braking performance portion of the analysis. The initial portion of the landing rollout was consistent with medium auto- braking performance. As groundspeed approached 90 knots, the deceleration profile was consistent with application of maximum braking. The possibility of hydroplaning and/or degraded braking performance could not be confirmed or negated from the available data. The airplane braking coefficient $\mu_{airplane}$ representing braking capability as a function of the ratio of the deceleration force from the wheel brakes relative to the normal force acting on the wheels was in the 0.15 to 0.4 range which signifies a range from medium reported braking (RCC 3) on wet runway conditions to good braking. Performance data indicates that, using maximum braking and normal reverse thrust procedures combined with the reported wind and medium reported braking capability (RCC 3), the expected landing distance would have been 7,348 feet, giving a margin of about 750 feet on Runway 14. The higher than reported tailwind and the low runway friction in certain sections led to the airplane needing the entire length of the runway to stop. No airplane systems anomalies were noted.

FIGURE 1

OEM

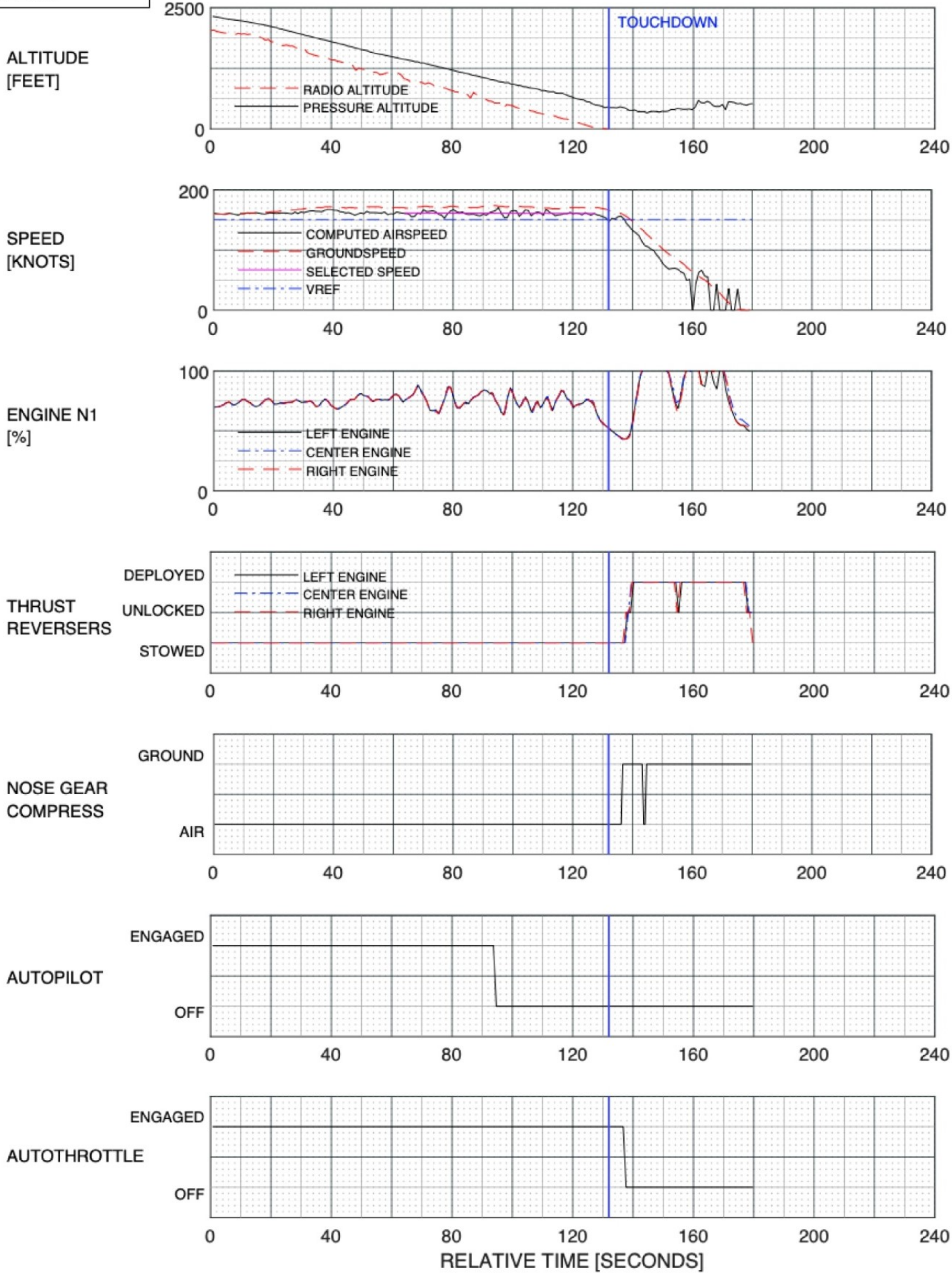
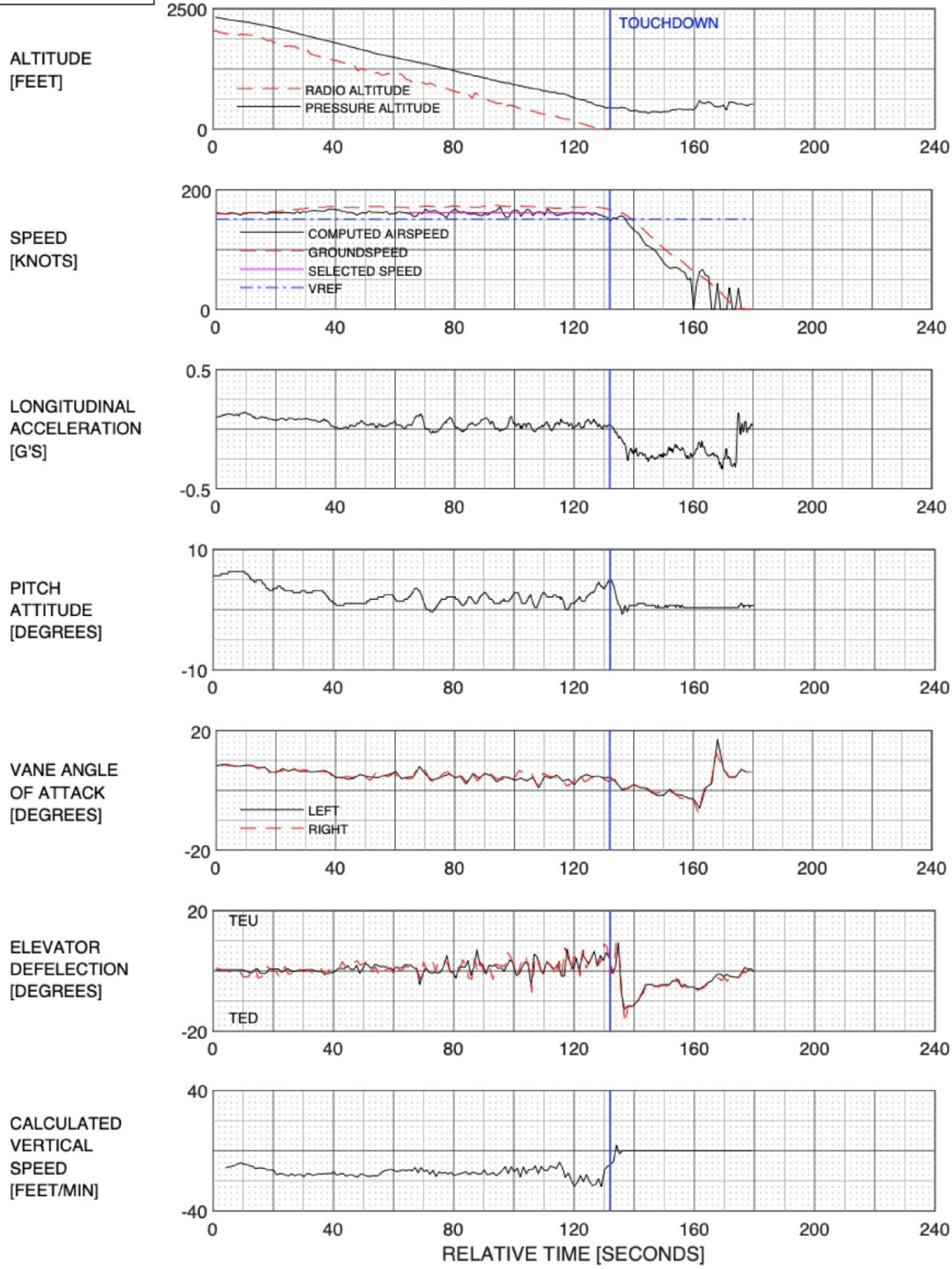

ALTITUDE
[FEET]
2500
0
TOUCHDOWN
RADIO ALTITUDE
PRESSURE ALTITUDE
0
40
80
120
160
200
240
SPEED
[KNOTS]
200
0
COMPUTED AIRSPEED
GROUNDSPEED
SELECTED SPEED
VREF
ENGINE N1
[%]
100
0
LEFT ENGINE
CENTER ENGINE
RIGHT ENGINE
THRUST
REVERSERS
DEPLOYED
UNLOCKED
STOWED
LEFT ENGINE
CENTER ENGINE
RIGHT ENGINE
NOSE GEAR
COMPRESS
GROUND
AIR
AUTOPILOT
ENGAGED
OFF
AUTOTHROTTLE
ENGAGED
OFF
RELATIVE TIME [SECONDS]

FIGURE 2

OEM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[FEET]
2500
0
TOUCHDOWN
RADIO ALTITUDE
PRESSURE ALTITUDE
SPEED
[KNOTS]
200
COMPUTED AIRSPEED
GROUNDSPEED
SELECTED SPEED
VREF
LONGITUDINAL
ACCELERATION
[G'S]
0.5
-0.5
PITCH
ATTITUDE
[DEGREES]
10
-10
VANE ANGLE
OF ATTACK
[DEGREES]
20
-20
LEFT
RIGHT
ELEVATOR
DEFELECTION
[DEGREES]
TEU
TED
CALCULATED
VERTICAL
SPEED
[FEET/MIN]
40
-40
0
40
80
120
160
200
240
RELATIVE TIME [SECONDS]

FIGURE 3

OEM

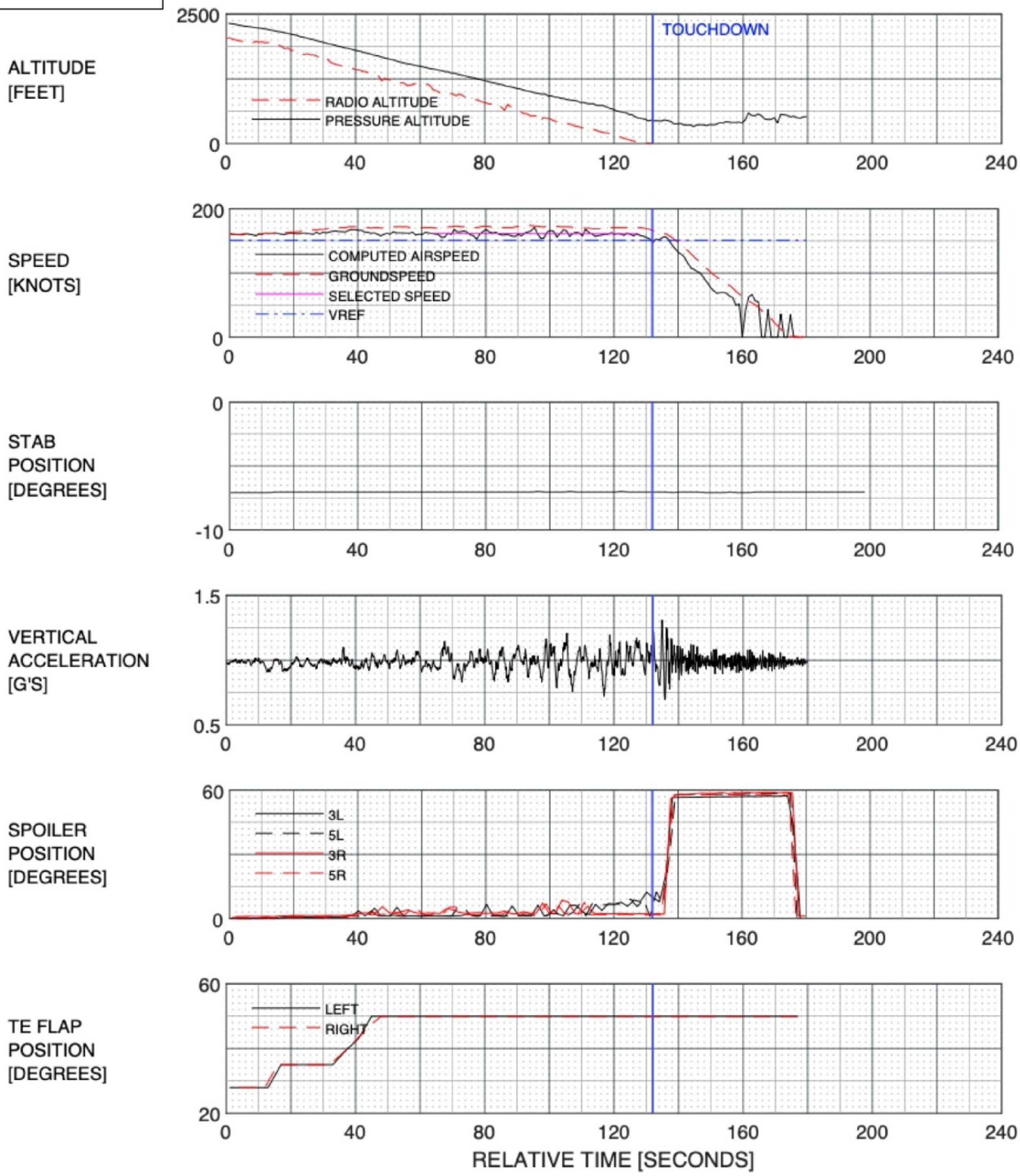

ALTITUDE [FEET]
TOUCHDOWN
RADIO ALTITUDE
PRESSURE ALTITUDE
SPEED [KNOTS]
COMPUTED AIRSPEED
GROUNDSPEED
SELECTED SPEED
VREF
STAB POSITION [DEGREES]
VERTICAL ACCELERATION [G'S]
SPOILER POSITION [DEGREES]
3L
5L
3R
5R
TE FLAP POSITION [DEGREES]
LEFT
RIGHT
RELATIVE TIME [SECONDS]

FIGURE 4

OEM

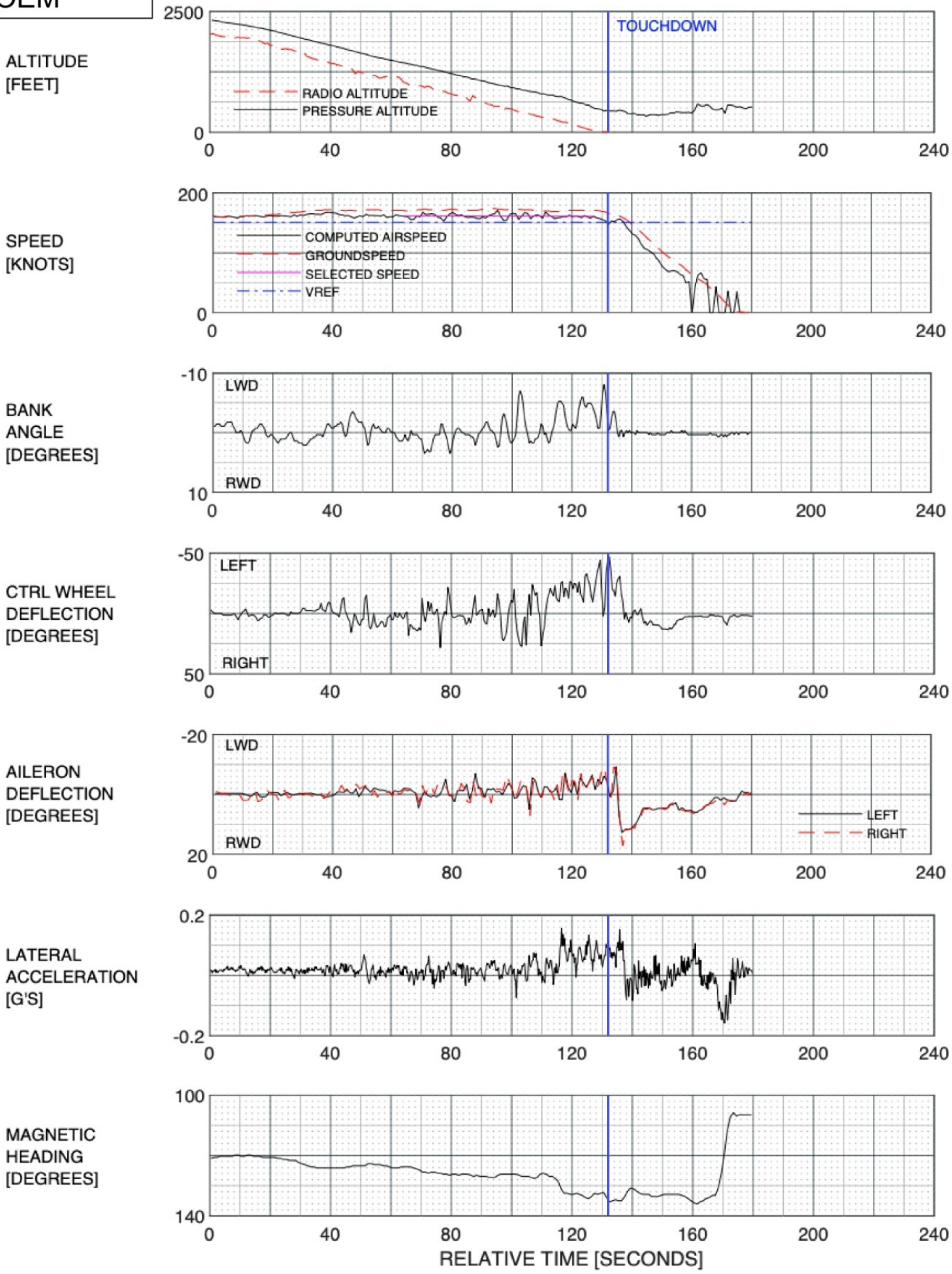

ALTITUDE [FEET]
2500
0
TOUCHDOWN
RADIO ALTITUDE
PRESSURE ALTITUDE
SPEED [KNOTS]
200
COMPUTED AIRSPEED
GROUNDSPEED
SELECTED SPEED
VREF
BANK ANGLE [DEGREES]
-10
10
LWD
RWD
CTRL WHEEL DEFLECTION [DEGREES]
-50
50
LEFT
RIGHT
AILERON DEFLECTION [DEGREES]
-20
20
LWD
RWD
LEFT
RIGHT
LATERAL ACCELERATION [G'S]
0.2
-0.2
MAGNETIC HEADING [DEGREES]
100
140
0
40
80
120
160
200
240
RELATIVE TIME [SECONDS]

FIGURE 5

OEM

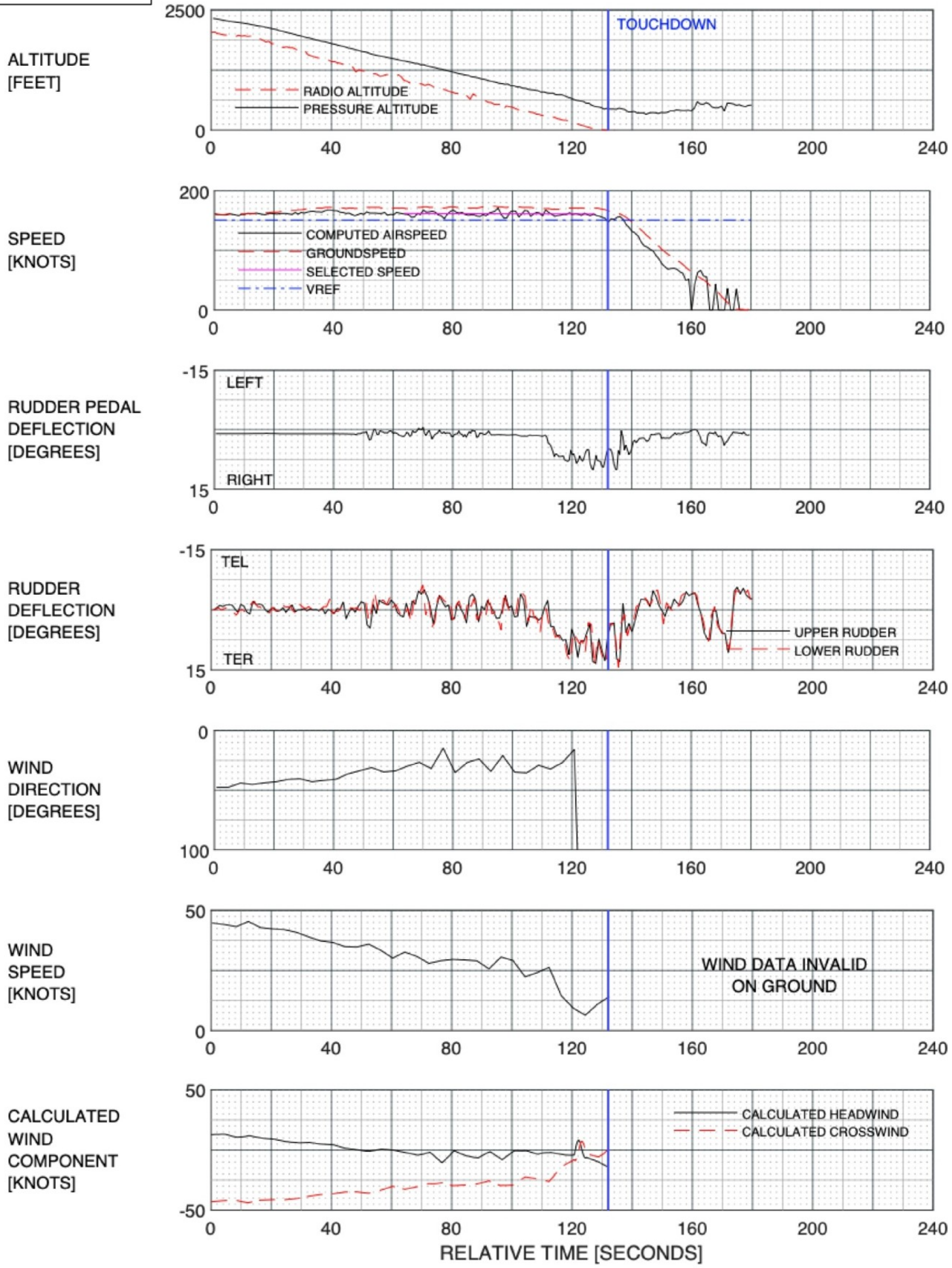

ALTITUDE [FEET]
2500
0
TOUCHDOWN
RADIO ALTITUDE
PRESSURE ALTITUDE
SPEED [KNOTS]
200
COMPUTED AIRSPEED
GROUNDSPEED
SELECTED SPEED
VREF
RUDDER PEDAL DEFLECTION [DEGREES]
-15
15
LEFT
RIGHT
RUDDER DEFLECTION [DEGREES]
TEL
TER
UPPER RUDDER
LOWER RUDDER
WIND DIRECTION [DEGREES]
100
WIND SPEED [KNOTS]
50
WIND DATA INVALID ON GROUND
CALCULATED WIND COMPONENT [KNOTS]
-50
CALCULATED HEADWIND
CALCULATED CROSSWIND
0 40 80 120 160 200 240
RELATIVE TIME [SECONDS]

FIGURE 6

OEM

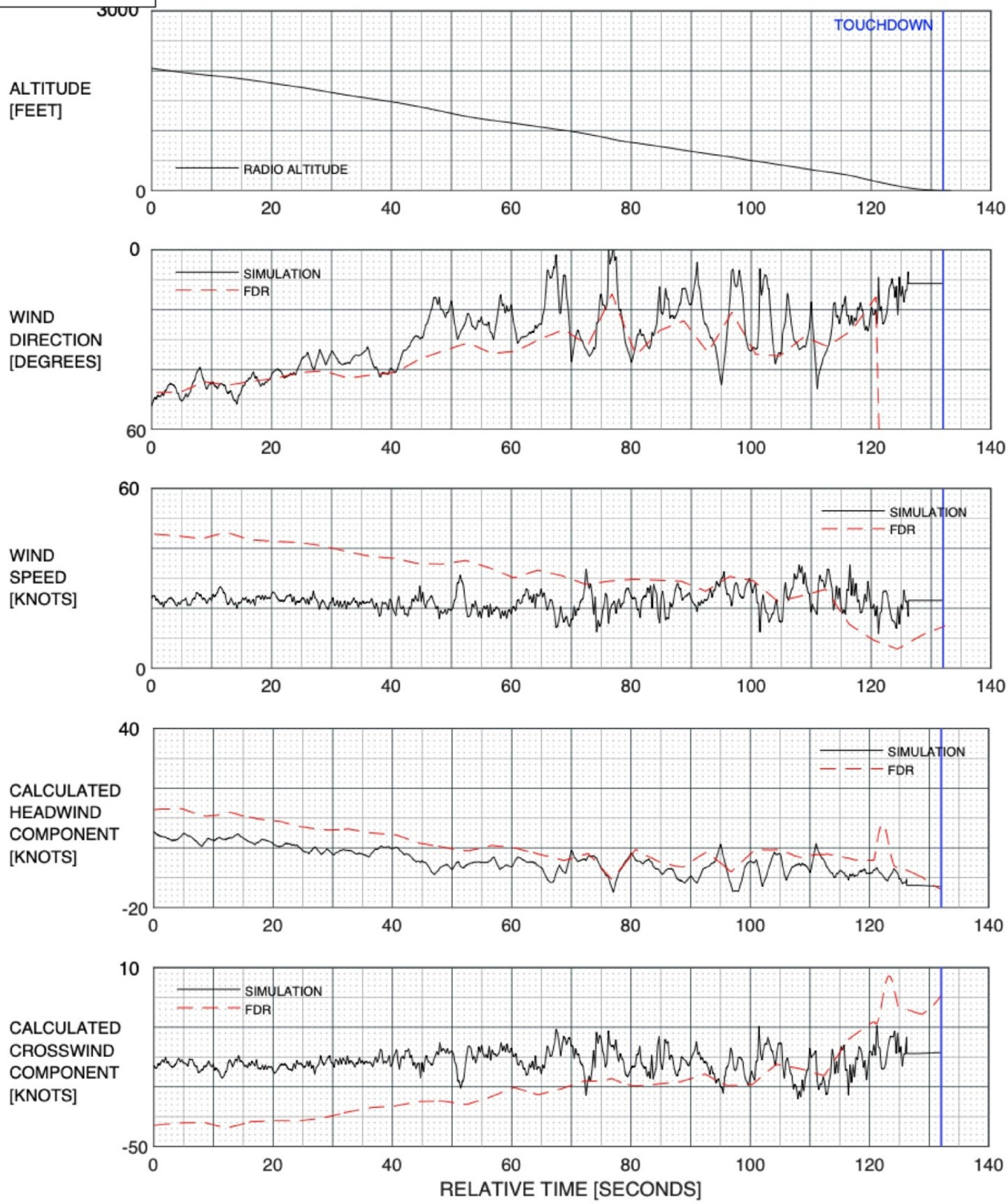

3000
ALTITUDE
[FEET]
TOUCHDOWN
RADIO ALTITUDE
0
0 20 40 60 80 100 120 140
0
WIND
DIRECTION
[DEGREES]
SIMULATION
FDR
60
0 20 40 60 80 100 120 140
60
WIND
SPEED
[KNOTS]
SIMULATION
FDR
0
0 20 40 60 80 100 120 140
40
CALCULATED
HEADWIND
COMPONENT
[KNOTS]
SIMULATION
FDR
-20
0 20 40 60 80 100 120 140
10
CALCULATED
CROSSWIND
COMPONENT
[KNOTS]
SIMULATION
FDR
-50
0 20 40 60 80 100 120 140
RELATIVE TIME [SECONDS]

FIGURE 7

OEM

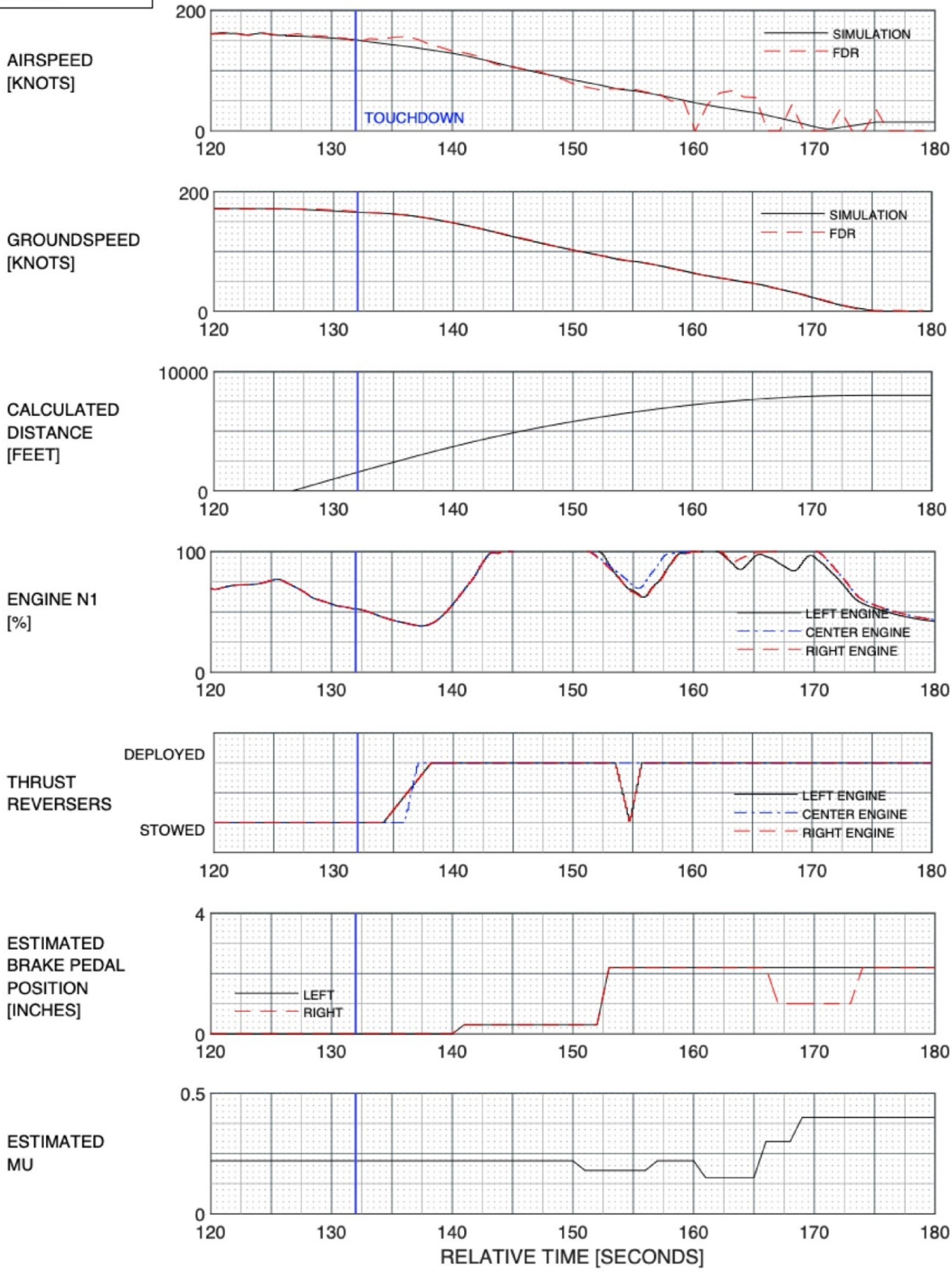
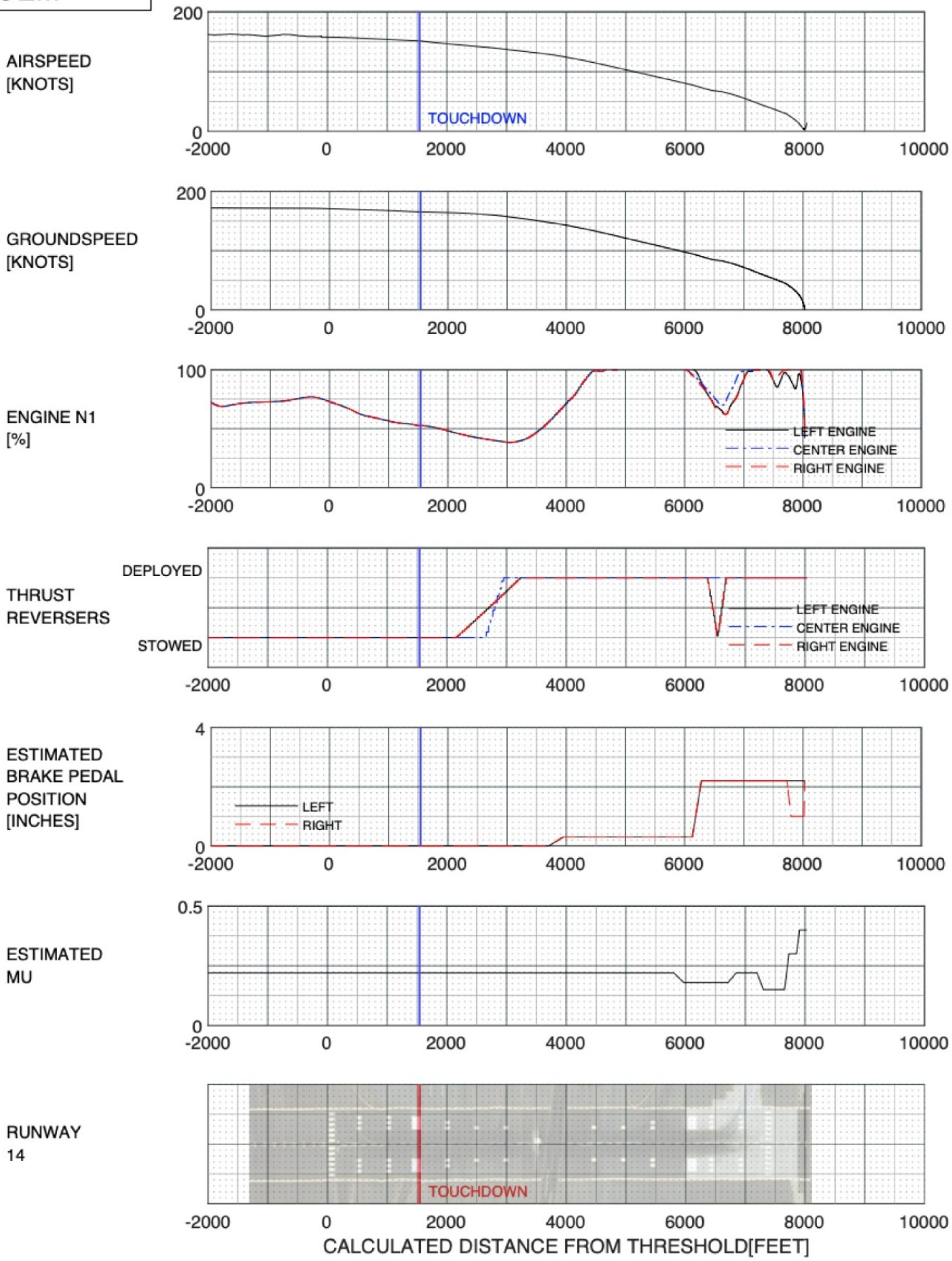

AIRSPEED [KNOTS]
SIMULATION
FDR
TOUCHDOWN
GROUNDSPEED [KNOTS]
CALCULATED DISTANCE [FEET]
ENGINE N1 [%]
LEFT ENGINE
CENTER ENGINE
RIGHT ENGINE
THRUST REVERSERS
DEPLOYED
STOWED
ESTIMATED BRAKE PEDAL POSITION [INCHES]
LEFT
RIGHT
ESTIMATED MU
RELATIVE TIME [SECONDS]

FIGURE 8

OEM


AIRSPEED
[KNOTS]
200
0
TOUCHDOWN
-2000
0
2000
4000
6000
8000
10000
GROUNDSPEED
[KNOTS]
ENGINE N1
[%]
100
LEFT ENGINE
CENTER ENGINE
RIGHT ENGINE
THRUST
REVERSERS
DEPLOYED
STOWED
ESTIMATED
BRAKE PEDAL
POSITION
[INCHES]
4
LEFT
RIGHT
ESTIMATED
MU
0.5
RUNWAY
14
CALCULATED DISTANCE FROM THRESHOLD[FEET]

## 1.17 Organisational and Management Information

The aircraft was operated by an FAA approved Scheduled Cargo Operator.

## 1.18 Additional Information

The FAA vide SAFO 19001 (Safety Alerts for Operators) dated 03/11/2019 addresses 'Landing Performance Assessments at Time of Arrival'. *SAFO 19001 'Landing Performance Assessment at Time of Arrival'*. The extract of relevant portions are as below:

*Landing Distance at Time of Arrival*. These distances are advisory performance data (i.e., not required by regulation) intended to provide a more accurate assessment of actual landing distance at time of arrival, considering factors that cannot be accurately predicted at time of preflight, such as runway contaminants, winds, speed additives, and touchdown points. These distances may be based upon the use of reverse thrust, ground spoilers, autobrakes, etc.

*Runway Surface Conditions.* The state of the runway surface: dry, wet, or contaminated.

- A dry runway is one that is clear of contaminants and visible moisture within the required length and the width being used.
- A wet runway is one that is neither dry nor contaminated.
- A contaminated runway is one where the runway surface conditions report includes the type and depth (if applicable) of the substance on the runway surface (e.g., water, dry snow, wet snow, slush, ice, frost, sanded, or chemical treatment).

***Table 1.*** Landing Distance Factors

The following are multipliers to the unfactored certificated (AFM) landing distances.

| | *Runway Condition Code* | | | | | | |
|---|---|---|---|---|---|---|---|
| **Braking Action** | 6 (Dry) | 5 Grooved /PFC Good | 5 Smooth Good | 4 Good to Medium | 3 Medium | 2 Medium to Poor | 1 Poor |
| **Turbojet, No Reverse** | 1.67 | 2.3 | 2.6 | 2.8 | 3.2 | 4.0 | 5.1 |
| **Turbojet, With Reverse** | 1.67 | 1.92 | 2.2 | 2.3 | 2.5 | 2.9 | 3.4 |

***Safety Margin***. The operational landing distance (OLD) used for a time of arrival landing assessment includes a safety margin of at least 15 percent when based on manual wheel braking.

***Autobrake Usage***. While autobrakes are part of the aircraft's landing configuration, the landing distance assessment is not intended to force higher than necessary autobrake selection. For operations when the runway is dry or wet if the manual braking distance provides a 15 percent safety margin, then the braking technique may include a combination of autobrakes and manual braking even IF the selected autobrake landing data does not provide a 15 percent safety margin.

***Touchdown Point***. The touchdown point used in the performance data assessment reflects the assumed air distance. Operational landing data usually includes an allowance for 1,500 feet or 7 seconds of air distance from the threshold to touchdown. An air distance as short as 1,000 feet may be used IF an operator's landing assessment procedures include enhancements to minimize the risk of overruns or undershoots, including:

(a) Training in touchdown control and short field landing techniques.

(b) Identification of required touchdown point and training to assure go-around procedures are initiated if unable to achieve a suitable touchdown point.

(c) Approach guidance and runway markings on the specific runway are consistent with a shorter air distance.

(d) Operational data (without the need for interpolation) are provided to the crew for the specific runway, conditions, and aircraft landing configuration.

(e) The flight techniques assumed in the creation of the performance data used for a shorter air distances are based on flight techniques to be used in the shorter air distance operation.

For example, the assumed speed bleed off used in the performance data needs to be consistent with the trained flight techniques for flaring the aircraft.

NOTE: If no other information is available, the autoland or other similar low visibility guidance system may be assumed to be consistent with the 7 second air distance.

***Recommended Action:*** Directors of safety and directors of operations (part 121); directors of operations (part 135, and 125), program managers, (part 91K), and pilots (part 91) should take appropriate action within their operation to address the safety concerns with landing performance on wet or contaminated runways discussed in this SAFO. Operators should develop procedures for flight crews to assess landing performance based on conditions existing at time of arrival, distinct from conditions forecast prior to departure. Those conditions may include weather, Runway Condition Code (if provided), FICON report (if provided), the airplane's weight, braking systems to be used, and any other conditions the operator deems necessary to conduct a safe landing, such as Pilot Reports of Braking action. Once the actual landing distance is determined at the time of arrival, an additional safety margin of at least 15 percent should be added to actual landing distance. Except under emergency conditions flight crews should not attempt to land on runways that do not meet the assessment criteria and safety margins as specified in this SAFO.

## 1.19 Useful or Effective Investigation Techniques

Nil

## 2. ANALYSIS

### 2.1 GENERAL

(a) There was no reported issue either with the maintenance of aircraft or its performance including the engines.

(b) The runway friction coefficient for runway 14 was assessed and found to be within tolerance limits as prescribed by the regulator.

(c) Barring FDR which was under MEL till next heavy maintenance, no abnormality was reported on the aircraft systems or instruments prior to or after the incident.

(d) Runway Overrun Protection Systems (ROPS) was neither required nor installed. The system would have provided timely information on the remaining landing distance available to the flight crew.

(e) The aircraft flew a stabilised approach to runway up to 50’ above the threshold. The First Officer initiated a flare manoeuvre that resulted in a delayed touchdown within the touchdown zone of the runway. The touchdown was within normal structural limits. The spoilers got deployed and First Officer deployed the reverse thrust. The braking parameters were not recorded so were not available for investigation. During the last approximately 2000’ of landing roll, the crew commenced the cancellation of the reverse thrust momentarily and then redeployed the reverse thrust to maximum. The left engine had visible flames emerging from it on two occasions in short succession. The aircraft crossed taxiway E1 and came to a stop with the aircraft heading left of runway 14. During the process aircraft overrun, the Nose gear was beyond the runway. Crew subsequently attempted a right turn to vacate the runway but decided against it since the runway lights could have been damaged.. Fire and rescue services approached the aircraft and the crew were advised to shut down the engines.

### 2.2 Weather

Prevailing winds, visibility, status of rain and runway surface condition was provided in the relevant METARs through DATIS and passed on to the flight crew while imparting landing clearance. The weather encountered was as reported.

Minor variations of winds however were expected and encountered, though these variations have in no way affected the flight.

### 2.2.1 Runway Surface Friction Report

The Runway friction tests were conducted on 26 May 2020 and again shortly after the incident on 03 June 2020. The tests were conducted as per the DGCA regulations.

However, in case of heavy and continuous rain which is typical to the aerodrome in monsoon season, the runway may have flowing water which may be higher than the requirement for reporting wet runway. This could result in lower than expected braking action.

Approximately 3 hours prior to the incident flight, one of the landing aircraft reported braking action to be Poor for runway 14. Subsequently three other aircrafts landed on runway 14 but did not provide any report on braking action. The aircraft landing one hour after the incident aircraft reporting braking action as Medium.

It may be derived from the above that runway condition as reported by the ATC while correct from the ATC perspective does not always relate to braking action coefficient as reported by pilots.

## 2.3 Air Traffic Control

The Air Traffic controllers provided the aircraft with timely and accurate weather and runway surface conditions. The entire length of Runway 14 is visible from the ATC Tower. The ATC on observing that the aircraft is unable to turn and has possibly overrun the runway asked the crew to shut down the engines and activated the RFF services to approach the aircraft in a timely manner.

## 2.4 Flight Operations

The First Officer was the pilot flying for this sector. The First officer in his statement mentioned that they were aware of the limiting runway length for landing on runway 14. The planned landing was to be made with autobrake selection at medium and manual braking would be applied if required.

### 2.4.1 Airplane Performance Software (APS)

APS is the primary source the Flight Crew uses to determine takeoff and landing performance data and to calculate Contingency Weight & Balance data. The onboard tool provides comprehensive data entries to compute the required landing distances for the aircraft. There are several entries that need to be made for landing performance calculations. It is to be noted that the default reference for computation is DRY Runway conditions.

The data from the software was not available for the investigation. The investigation could not determine if data entry errors or default values were a factor in computing the landing distance performance.

#### 2.4.1.1 ***FAA - SAFO Guidance***

The margins for landing a turbojet aircraft with reverse thrust credit on a wet runway with good braking action is 1.92. i.e. an additional 92% of runway would have been available if the landing assessment at time of arrival was computed as per the SAFO 19001 dated 03/11/2019 (Table in 1.18 Refers). The SAFO also states that the touchdown point used in the performance data assessment reflects the assumed air distance. Operational landing data usually includes an allowance for 1,500 feet or 7 seconds of air distance from the threshold to touchdown. An air distance as short as 1,000 feet may be used IF an operator's landing assessment procedures include enhancements to minimize the risk of overruns or undershoots.

If the APS module was used for a wet runway with good braking action, the margin for stopping would have been 92% higher than the available wet runway with good braking action.

### 2.4.2 Crew Perspective

Flight crew were not made available for an interview. The flight crew perspective therefore is limited to an initial statement submitted jointly by both crew members.

### 2.4.3 Operational Procedure

#### 2.4.3.1 FDR Data

The AAIB, India was unable to process the FDR data due to the non- availability of the data-frame reference and missing data parameters. The FDR was submitted to NTSB for Analysis, which was conducted using data-frame documentation for a similar MD11 aircraft and Desktop simulation software to produce estimates for data parameters that were not recorded.

#### 2.4.3.2 FDR Readout

NTSB was requested for a pilot handling report, since neither the relevant CVR recording nor the FDR readout provided the investigators with the required basic parameters for carrying out analysis. The FDR was under MEL for FAR non-mandated parameters. The CVR was overwritten since it was not secured after the incident.

The initial NTSB report received confirmed that:

(a) The aircraft speed profile during descent to 10,000′ was normal.

(b) Speed brakes were deployed as required for normal operation.

(c) The aircraft speed profile during initial approach (10,000′ to 2,000′) was normal.

(d) Final approach (2000′ to Touch down) speed was within the operational limits.

(e) When the aircraft was at approximately 200 ft Radio Altitude, recorded winds were 023/12 kts. i.e. 11 kts of crosswind component and 4 kts tailwind component. The reported winds at that time were almost the same i.e. 030/12 kts gusting to 22 knots.

(f) Reverse thrust was selected at approximately 2 seconds after touchdown.

(g) The throttle positions were not recorded, but it could be seen that "maximum reverse N1" reached approximately 6.4 seconds after the reversers were deployed. Normal procedure is to stow the thrust reversers at 80 knots. In this case, the reverser began to stow, but the reversers were redeployed and with maximum reverse thrust.

(h) **Autobrake, brake pedal and other wheel braking parameters and settings were not recorded.**

No anomalies were noted in any engine parameter readings. The airplane maintained runway heading with normal variations until the groundspeed reached about 50 knots, when a left turn was initiated.

**In view of the missing FDR parameters, OEM carried out MD-11 desktop simulation to match the recorded flight data as closely as possible (to validate the recorded data and to produce estimates for parameters that were not recorded). As the <u>data-frame document was not available for the subject aircraft</u>, data-frame documentation for a similar MD11 aircraft was used by Boeing for converting raw format data to engineering units, though it might not have been as exact as it should be.**

### 2.4.3.3 Desktop Simulation (By Boeing)

Following information was available from FDR data:

(a) Autopilot was disengaged at approximately 500 feet radio altitude with auto-throttle engaged.

(b) As the aircraft approached 50 feet radio altitude, the aircraft pitch attitude was increased to approximately 4 degrees, arresting the sink rate to about 5 feet per second at touchdown.

The simulation carried out emphasized on aircraft braking and estimated runway friction throughout the landing roll.

(c) The selected airspeed for approach was 162 knots (Vref+11). Speeds were within the operational range and no limits were exceeded.

(d) ground spoilers were deployed to full deflection upon touchdown and remained deployed until the aircraft came to a complete stop.

(e) all three thrust reversers deployed as expected after touchdown. After approximately 15 seconds, thrust reversers began transitioning to Stow when they were once again deployed to maximum until the aircraft came to a complete stop.

**Certain assumptions made were:**

(a) "Relative Time" used for plotting these parameters was the ***elapsed time from an arbitrary point initialized*** as the start of the segment of flight being analysed.

(b) For an aircraft with the profile (as of the subject aircraft), MD-11 Flight Crew Operating Manual (FCOM), Vref speed comes to be 151 knots (by interpolation).

(c) Touchdown likely occurred at approximately 132 seconds, about 1,540 feet past the runway threshold of runway 14 as indicated by a slight decrease in longitudinal acceleration and an increase in normal load factor.

With the above assumptions and approximations, touchdown has been estimated to be at **1,540 feet** past the runway threshold. Computed airspeed at that time was approximately 150 knots and ground speed of approximately 165 knots. The calculated tailwind component at touchdown was approximately 15 knots with a left crosswind component of approximately 17 knots.

Kinematic consistency analysis was conducted for which FDR recorded airspeed data and the integrated inertial data, along with the full aircraft aerodynamic model, was used to estimate the wind profile. However, various assumptions, approximations and extrapolations were required for carrying out the above analysis.

**Based on the modeling, Boeing has deduced that:**

(a) the aircraft crossed Runway threshold at a radio altitude of approximately 50 feet and calibrated airspeed of approximately 158 knots with an approximate tailwind component of 15 knots.

(b) At time 132 seconds, main gear touchdown occurred 1,540 feet past runway threshold at a calibrated airspeed of approximately 150 knots.

(c) Deployment of ground spoilers immediately followed as the aircraft de-rotated over the span of approximately four seconds. During this time, longitudinal deceleration increased to an average value of 0.2 g's. Two seconds following nose gear compression, thrust reversers were deployed to full reverse thrust as characterized by an increase in engine N1 to 100%.

(Since braking level parameters were not recorded and runway friction was unknown, it was not possible to separate the two with certainty. Therefore, assumptions were made regarding braking level, and the braking coefficient (which includes the runway friction) was derived based on certain assumptions.)

**The landing roll analysis is as follows: (in phases)**

(a) From time 132 to 140, little or no braking is observed. Since MED auto-brakes target a deceleration level, not a target braking level, this section is consistent with MED auto-brake use. The deceleration came primarily due to reverse thrust, with the µairplane not a significant contributor in this phase.

(b) The second phase, from time 140 to 152 needed an increased braking level. After time 152, since the thrust reversers had been redeployed, it was assumed that maximum braking had been applied and it is in this phase that variations in µairplane become apparent. The aircraft braking coefficient at 5,900 feet beyond the threshold (~2,200 feet runway distance remaining) is estimated to be a value of approximately 0.22 which is characteristic of good braking action on damp/wet surface conditions.

(c) At approximate time 155 seconds, 6,200 feet beyond the threshold (~1,900 feet runway distance remaining) and a computed airspeed of approximately 70 knots, the thrust reversers began transitioning to stow. In this segment of the landing rollout, the estimated µairplane fell from 0.22 to approximately 0.17.

(d) Three seconds later, a manual re-deployment back to full reverse thrust was initiated. At approximately this time, manual braking is assumed to have been increased to max braking until a complete stop was achieved.

(e) The total stopping distance from touchdown to a complete stop was approximately 6,567 feet. When the groundspeed reached 34 knots, an approximate 26 degree left turn is observed in the recorded flight data, leaving the aircraft pointed approximately 30 degrees to the left of centerline.

(f) About 45 seconds later, the aircraft made a right turn, crossing the end line, to a heading of about 232 degrees (perpendicular to the runway) and came to a stop on the blast pad with the right main landing gear measured to be approximately 7 meters (~23 feet) beyond the end of the runway.

The possibility of hydroplaning and/or degraded braking performance could not be confirmed or negated from the available data. The airplane braking coefficient μ airplane representing braking capability as a function of the ratio of the deceleration force from the wheel brakes relative to the normal force acting on the wheels was in the 0.15 to 0.4 range which signifies a range from medium reported braking (RCC 3) on wet runway conditions to good braking.

The OEM report in its conclusion states that significant assumptions were made due to lack of FDR recorded data with regards to braking performance. The report is based on a simulation which is expected to closely replicate but not conclusively establish the parameters as would be the case if the FDR was available in full. There are inconsistencies in the thrust reverse timings being taken from 2 seconds after touchdown to 2 seconds after nose gear compression. The difference between Main Gear Touchdown and Nose Gear touchdown is 4 seconds. While the OEM has made an earnest effort in corroborating data, there were inconsistencies that left a few areas unanswered. Example: if the aircraft had touched down as per the OEM simulation and commenced the required deceleration, it was unlikely to have exceeded the landing distance available.

Given the areas that needed to be addressed the investigators sought evidence from other sources to contextualize the OEM report.

### 2.4.4 Ground (Recorded) Evidences

#### 2.4.4.1 SAGA Data Analysis

The SAGA report provided transponder-based aircraft information. As per the information from the report, the aircraft appeared to be stabilized at 2300′ while at 161 Kts of Ground speed. Subsequently the aircraft appeared to be high on approach followed by a late touchdown though subsequent deceleration appeared to be normal. It may be noted that SAGA does not have the capture rate as of the FDR.

Following table provides the SAGA data for reference purposes.

| SAGA Data Plots | | | | |
|---|---|---|---|---|
| **Time (IST)** | **Altitude (ft)** | **GS (Kts)** | **VS (fpm)** | **Remarks** |
| 12:09:54 | 2300 | 161 | -640 | A/C Stable On Approach |
| 12:10:34 | 1725 | 171 | -1088 | A/C Stable On Approach |
| 12:11:25 | 1000 | 174 | -832 | A/C Stable On Approach |
| 12:11:40 | 800 | 171 | -768 | A/C Stable On Approach |
| 12:11:52 | 625 | 172 | -1024 | Abeam TXY E10 |
| 12:11:57 | 525 | 172 | -768 | Over Landing Threshold |
| 12:12:08 | 400 | 160 | -320 | Abeam TXY N / N1 |
| 12:12:14 | 375 | 132 | -192 | Abeam TXY F5 |
| 12:12:22 | 0 | 96 | 0 | Past E4 TXY |
| 12:12:32 | 0 | 56 | 0 | Runway 32 Threshold |
| 12:12:38 | 0 | 38 | 0 | Abeam TXY W1 |
| 12:12:43 | 0 | 10 | 0 | Excursion Occurs |

While the SAGA reports have inaccuracies, they were indicative of a higher speed during approach and a subsequent late touchdown.

### 2.4.4.2 CCTV Analysis

The CCTV camera arrangements provide visual evidence from the time the aircraft crosses the runway threshold to the point of touchdown and a separate camera installation shows the aircraft approaching the end of runway 14. The CCTV video evidence provided a more accurate point on the runway where the aircraft main landing gears contacted the runway. The relevance to determine this point on the runway is to establish the deceleration effort required to bring the airplane to a complete stop.


**Fig – 30**: (CCTV 1 Image 5) shows All main landing gear having contacted the runway surface. The nose wheel has still not contacted the runway. There is no spoiler deployment over the wings at this point.

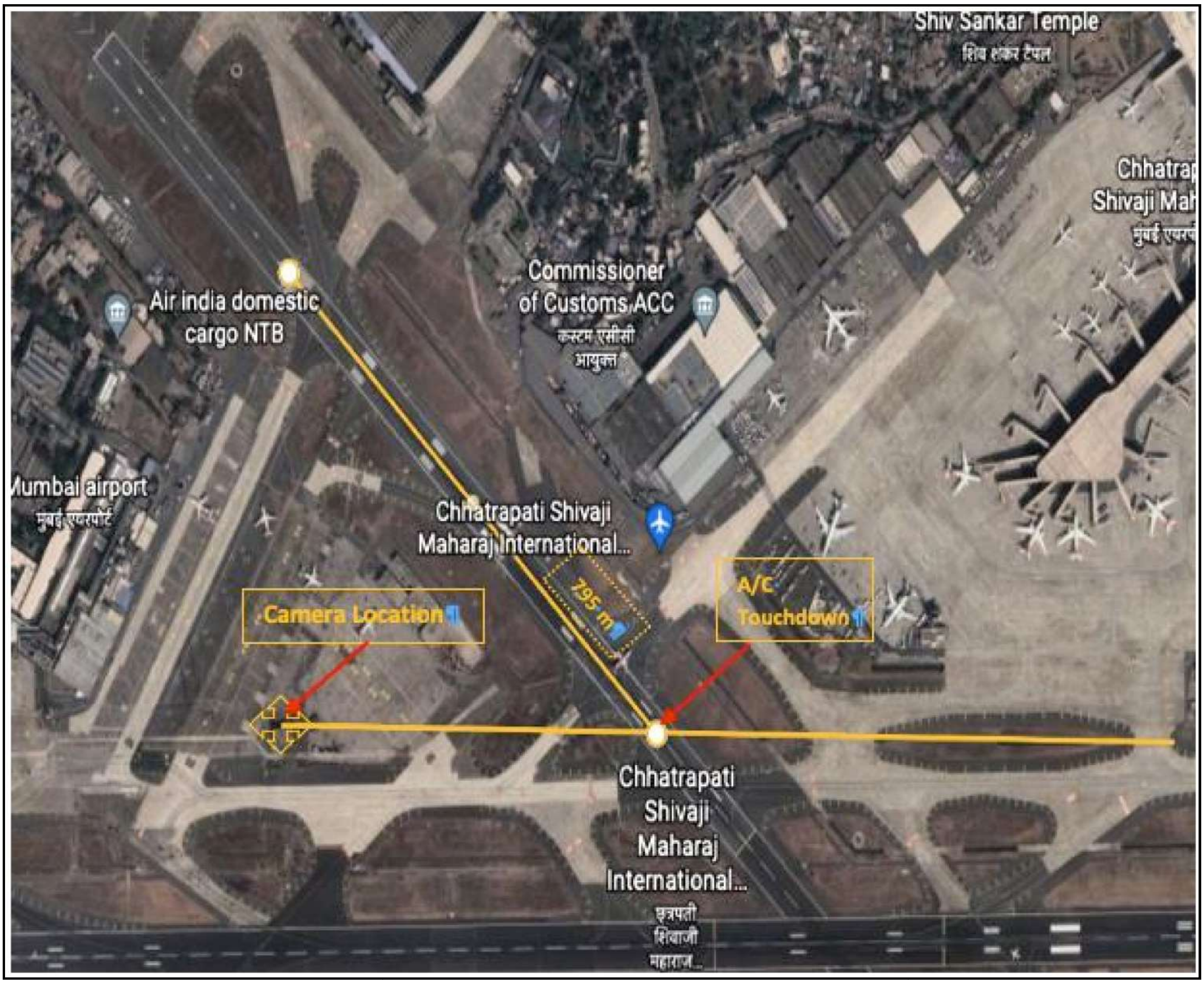



**Fig – 31**: The Google earth plot (Screenshot): Depicts Touchdown point of FDX5033.

The fig-31 shows approximately 795 meters (2608 feet) being consumed prior to the aircraft having touched down on all main landing gears. There is no visible deployment of wing spoilers or reverse thrust up to this point on the video. Due to the geometric limitation the camera does not cover the aircraft movement much beyond this point and the runway intersection is not captured. The SAGA radar capture and the OEM report (aircraft touchdown) shows the aircraft ground speed of 160 Kts (SAGA) and 165 Kts (OEM Report) which is significantly high considering an extended flare maneuver.

The OEM report factors the aircraft landing distances computed from an arbitrary point and using simulation models to compute the landing performance of the aircraft. The CCTV evidence provides a calibration point for the model in order to determine a more precise geographical point on the runway. Superimposing the above point (instead of arbitrary point) in the simulation model, various distances on the runway could be worked out.

From the above it is evident that the aircraft would require to maintain a high stop effort. Therefore the runway surface condition or friction coefficient may not be contributory to the degree stated in the OEM report. The table below shows the margins computed by the OEM report and includes distances based on the more acurate touchdown point as captured by the CCTV cameras.

| Constant Tailwind Component (knots) | Reported Braking* | Deceleration Profile** | Landing Distance (feet) | Touchdown point as per CCTV | Stopping Distance from Touchdown (feet) | Runway length (feet) | Runway Length Remaining after touchdown (feet) | Runway Length Required after touchdown (feet) | Margin after late touchdown (feet) |
|---|---|---|---|---|---|---|---|---|---|
| -5 | Good | 1 | 5950 | 2608 | 4953 | 8107 | 5499 | 7561 | **546** |
| -5 | Good | 2 | 5881 | 2608 | 4005 | 8107 | 5499 | 6613 | 1494 |
| -5 | Medium | 1 | 7348 | 2608 | 5472 | 8107 | 5499 | 8080 | **27** |
| -5 | Medium | 2 | 6836 | 2608 | 4960 | 8107 | 5499 | 7568 | **539** |
| -15 | Good | 1 | 7001 | 2608 | 4953 | 8107 | 5499 | 7561 | **546** |
| -15 | Good | 2 | 6870 | 2608 | 4822 | 8107 | 5499 | 7430 | **677** |
| -15 | Medium | 1 | 8856 | 2608 | 6608 | 8107 | 5499 | 9216 | **-1109** |
| -15 | Medium | 2 | 7922 | 2608 | 5874 | 8107 | 5499 | 8482 | **-375** |

*Based upon TALPA ARC AC 25-32 Runway Condition Codes: Good – RCC 5 Medium – RCC 3

** Hypothetical scenarios employing the following deceleration devices:

Profile-1: Max Reverse thrust to 80 KIAS, Reverse Idle to 60 KIAS, Forward Idle to stop, Max Manual Anti-skid

Profile-2: Max Reverse thrust to stop, Max Manual Anti-skid braking

It can be seen from above that, once the aircraft had touched down, the margins remaining for stopping with MAX Manual Braking were less than 700 feet except in 1 case (Profile 2). The crew would not likely have applied and maintained MAX Manual braking from initiated cancelling of reverse thrust at 80 kts and then redeployed the reverse thrust to maximum. The transition time of reverse thrust to idle and back to full further reduces the deceleration capability of the aircraft. Therefore, profile 1 with the assumption of maximum braking by the crew after touchdown and the reverse thrust credit till 80 kts would have provided a margin between 546 feet and 27 feet depending on the runway friction at the time. The crew had selected autobrake Medium for landing. The factor of time the autobrake was at medium to the transition of Maximum manual braking would further reduce the landing margins from the table above.

***Note:*** The CCTV coverage was obtained and the cameras were high definition cameras and provided the significant portion of the aircraft landing profile. The limitation of the camera physical location was factored in while establishing the location of the aircraft touchdown with a higher accuracy than the other available evidence. The CCTV coverage shows the aircraft right hand main landing gear touching down at approximately 2608 feet from the landing threshold for Runway 14. This information establishes more accurately the touchdown point definition and the remaining calculations provided by OEM when factored from this reference point are indicative of the fact that the aircraft would have needed higher than planned deceleration from this point to accomplish the landing roll as intended.

## 2.5 Comparison of Available Evidence

After receiving the OEM report for the FDR the reason for the overshoot could not be positively established. The aircraft should have stopped well within the limits of the runway based on the OEM assessment deduced from the FDR and simulation data.

On the other hand, SAGA report was indicative of a high energy approach with a very late touchdown. However, SAGA data does not provide the accuracy of data required to establish the overrun and cannot be used as standalone evidence.

The CCTV Video recording from the first camera installation provides the coverage of the aircraft approaching over the aerodrome perimeter wall up to the runway intersection. The CCTV provided a good and fairly accurate assessment of where the aircraft touchdown occurred.

Since the exact touchdown point was not established by the OEM reports, the CCTV recording were used to ascertain the touchdown point and the OEM report was referenced such that the computation remains the same after touchdown point based on the FDR and simulation data. The recalibrated data from the OEM when referenced to the actual touchdown point as captured by the CCTV provides the margin available to the crew. With Good Braking action and the deceleration profile assumption 1, the aircraft had 546’ of margin assuming the crew applied Maximum Manual braking throughout the landing roll.

The Runway friction tests were conducted as per the regulatory standards and the results were acceptable. The possibility of variations between reported surface condition and pilot reported braking action have been discussed earlier in the report.

Given the aircraft touchdown point, the aircraft was already critical for landing distance with MAX Manual braking on a WET runway. The lower likelihood of the crew maintaining MAX Manual braking thereafter was indicative to the causation of the runway overrun.

## 3. CONCLUSIONS

### 3.1 FINDINGS

(i) The runway surface was wet with flowing water due to continuous rain.

(ii) The number 1 engine had flames from the exhaust on two occasions during the later stages of the landing roll.

(iii) The aircraft had no defects relating to the deceleration devices required for the landing

(iv) The crew inputs for the performance calculation tool could not be verified

(v) The crew thrust lever and brake control inputs during the landing could not be confirmed due to lack of FDR data.

(vi) Runway friction tests carried out shortly after the incident shows the friction levels to be within limits as per the DGCA regulations

(vii) The aircraft touched down approximately 2,608 feet beyond the runway threshold at $V_{REF}$ of 151 Kts.

(viii) The aircraft had 27 feet margin from the actual touchdown point (CCTV) based on maximum manual braking and the normal use of reversers with a 5 kts tailwind and medium reported braking action.

(ix) Based on the actual touchdown location the available runway margin was limiting to the point the aircraft overshot the runway.

## 3.2 CAUSES

**Probable Cause**: A delayed touchdown followed by routine deceleration increased the landing distance required resulting in the aircraft overrun the runway.

***Contributing Factors:***

(a) Weather conditions resulting in tailwinds and wet runway surface.
(b) Initiation of cancellation of reverse thrust with insufficient runway remaining.

## 4. SAFETY RECOMMENDATIONS

4.1 DGCA may devise a methodology to ensure availability of flight data record as per CAR requirements for investigation purposes.
4.2 DGCA may ensure the amendments in the CAR Section - 4, Aerodrome Standards & Licensing, Series 'B', Part I, Issue II dated 26$^{th}$ August 2015 regarding the reporting of runway conditions are meticulously followed by all aerodromes operators.

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