State of Israel
Ministry of Transport and Road Safety
Accidents and Incidents Aviation Investigation

# Safety Investigation Report - Final

**(Final Investigation Report)**

## Incident File No. 38-21

## Fuel Leak that led to Engine Shutdown followed by diversion to an Alternate

| | |
|---|---|
| **Date** | **October 31, 2021** |
| **Aircraft** | **Boeing 787-9** |
| **Registration** | **4X-EDA** |
| **Location of event** | **Flight Bangkok to Tel Aviv** |

**For Safety Purposes Only**

The Investigations conducted by the Israeli Investigation Office (AIAI) are in accordance with Annex 13 to the ICAO Convention on International Civil Aviation, and the Israeli Aviation Law 2011, chapter 7, and its respective Aviation regulations.

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Accordingly, it is not appropriate that AIAI reports should be used to assign fault or blame or determine liability, since neither the investigation nor the reporting process has been undertaken for that purpose.

This report has been translated to the English language for other parties' convenience, and should adhere to the Original report in the Hebrew language - In any case of abstruseness or misunderstanding, the original report in the Hebrew language is taking over.

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# Safety Investigation Report - Final
# (Draft Investigation Report)

## Incident File No. 38-21

## Synopsis

On October 31, 2021, at 19:08 UTC, a Boeing 787-9 aircraft, registration 4X-EDA, departed from Bangkok airport (BKK) to Tel Aviv (TLV). The aircraft was operated by El Al (hereinafter: "**The Company**"/"**The Operator**") as scheduled flight, reg: LY082. Shortly after take-off a "Fuel Imbalance" message illuminated on EICAS. After approximately 2.5 hours of flight, a "Fuel Disagree" EICAS message came on. Dealing with the "Fuel Disagree" message has led the crew to conduct "Fuel Leak" Checklist, at the end of which the LH engine was shutdown according to the checklist.

The crew declared emergency, called "MAYDAY", diverted to and landed in India's Goa airport (GOI). Landing was completed with no further unusual events.

The company informed the Chief Investigator of Israel, who decided to open an investigation after the Indian Investigation Authority decided that it did not intend to investigate the incident.


**The subject aircraft**

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## ABBREVIATIONS

| | |
|---|---|
| **Aircraft** | **Incident aircraft** |
| **AHM** | **Aircraft Health Management** |
| **AME** | **Aircraft Maintenance Engineer** |
| **APU** | **Auxiliary Power Unit** |
| **ARC** | **Airworthiness Review Certificate** |
| **ARFF** | **Aerodrome Rescue and Firefighting** |
| **ATC** | **Air Traffic Control** |
| **ATD** | **Actual Time of Departure** |
| **ATIS** | **Air Traffic Information Services** |
| **ATPL** | **Air Transport Pilot's License** |
| **CB** | **Cumulonimbus clouds** |
| **CK VLV** | **Check Valve** |
| **CL** | **Check List** |
| **CPDLC** | **Controller Pilot Data Link Communications** |
| **CPT** | **Captain** |
| **CSN** | **Cycles Since New** |
| **CVR** | **Cockpit Voice Recorder** |
| **DFDR** | **Digital Flight Data Recorder** |
| **DME** | **Distance Measuring Equipment** |
| **DOW** | **Dry Operating Weight** |
| **EAFR** | **Enhanced Airborne Flight Recorder** |
| **ECL** | **Electronic Check List** |
| **EICAS** | **Engine Indication and Crew Alerting System** |
| **ELT** | **Emergency Locator Transmitter** |
| **FAA** | **Federal Aviation Administration, United States of America** |
| **FCOM** | **Flight Crew Operations Manual** |
| **FCP** | **Fuel Control Panel** |
| **FCTM** | **Flight Crew Training Manual** |
| **FDAF** | **Flight Data Acquisition Function** |
| **FDR** | **Flight Data Recorder** |
| **FDTL** | **Flight and Duty Time Limitations** |
| **FIM** | **Fault Isolation Manual** |
| **FM** | **Follow Me vehicle** |
| **FMC** | **Flight Management Computer** |
| **FO** | **Co-Pilot/ First Officer** |
| **FOD** | **Foreign Object Debris** |
| **FQIS** | **Fuel Quantity Indication System** |
| **FQMS** | **Fuel Quantity Management System** |
| **FRB** | **Flight Report Book** |
| **FRM** | **Fault Reporting Manual** |

| | |
|---|---|
| **GPS** | **Global Positioning System** |
| **IATA** | **International Air Traffic Association** |
| **ICAO** | **International Civil Aviation Organization** |
| **IFR** | **Instrument Flight Rules** |
| **ILS** | **Instrument Landing System** |
| **IR** | **Instrument Rating** |
| **LH** | **Left Hand** |
| **MCC** | **Maintenance Control Center** |
| **MEL** | **Minimum Equipment List** |
| **METAR** | **Meteorological Terminal Air Report** |
| **NNC** | **Non-Normal Checklist** |
| **NTSB** | **National Transportation Safety Board** |
| **OCC** | **Operations Control Center** |
| **OFP** | **Operational Flight Plan** |
| **OM-A** | **Operation Manual part A** |
| **PDR** | **Pilot Defect Report** |
| **PF** | **Pilot Flying** |
| **PIC** | **Pilot in Command** |
| **PM** | **Pilot Monitoring** |
| **QNH** | **Pressure setting to indicate elevation** |
| **QRH** | **Quick Reference Handbook** |
| **RADAR** | **Radio Detection and Ranging** |
| **RCP** | **Refuel Control Panel** |
| **RDC** | **Remote Data Concentrator** |
| **RH** | **Right Hand** |
| **SCT** | **Scattered** |
| **TAF** | **Terminal Aerodrome Forecast** |
| **SMC** | **Surface Movement Control** |
| **SSE** | **Safety Significant Events** |
| **TCAS** | **Traffic Collision Avoidance System** |
| **TOW** | **Take-off Weight** |
| **(u)NNC** | **Un-annunciated Non-Normal Checklist** |
| **UTC** | **Universal Time Coordinated** |
| **VABB** | **Mumbai Airport** |
| **VFR** | **Visual Flight Rules** |
| **VOGO/GOI** | **Goa Airport** |
| **VTBS/BKK** | **Bangkok Airport** |
| **ZFW** | **Zero Fuel Weight** |

# 1. Factual information

## Background

The aircraft departed Israel for a series of flights at the company's Far East destinations. Four flight legs were planned: Tel Aviv (TLV) – Phnom Penh (PHN) – Phuket (HKT)– Bangkok (BKK) – Tel Aviv (TVV). The fuel leak event occurred on the 4th leg, from Bangkok to Tel Aviv.

The 1st leg began as flight LY081, which departed Tel Aviv on Oct. 31, 2021 at 21:37 UTC and landed in Phnom Penh, Cambodia on Oct. 31 at 07:57 UTC.

The 2nd leg continued after about two hours on the ground in Phnom Penh. The aircraft took off from Cambodia on Oct. 31 at 09:38 UTC and landed in Phuket, Thailand on Oct. 31 at 11:01 UTC.

A 3rd leg began after about four hours on the ground in Phuket. The aircraft took off as flight LY082 on Oct. 31 at 15:45 UTC and landed in Bangkok, Thailand on Oct. 31 at 17:45 UTC (Nov. 1, 2021 at 00:45 local time).

### 1.1 History of the flight

**The incident flight**, which was the 4th leg of the flight, began after about two hours on the ground in Bangkok. During this time, the aircraft was refueled and several passengers have boarded and joined those already on board. The aircraft took off as flight LY082 to Ben Gurion on Oct. 31, 2021 at 19:08 UTC (Nov. 1 at 02:08 local time).

On board this flight leg, there were 257 passengers and 19 crew members, including 4 pilots (double crew).

According to the Load Sheet, the aircraft was loaded with cargo which was approx. 2.1 tons heavier than planned in the flight plan. According to the flight crew (hereinafter: "**the crew**"), they were aware of the additional weight and determined that the added 1.5 tons of extra fuel, which were originally assigned for diversions due to enroute poor (stormy) weather, will also be sufficient for the additional cargo weight.

During initial climb after takeoff, while crossing 9,200 feet, an EICAS "Fuel Imbalance" message has illuminated, indicating unbalance of fuel between the Main fuel tanks.

After crossing altitude of 10,000 feet, the crew began dealing with the discrepancy. The crew detected that the L Main fuel tank quantity is lower by approx. 500 kg than the R Main fuel tank's quantity.

The crew initiated the "Fuel Imbalance" checklist and while executing it, they noticed a difference of 100 kg fuel between the **Calculated** total fuel quantity and the actual measured quantity (**Totalizer**). The difference was detected upon comparing, as per the checklist, the **Totalizer** with the **Calculated** quantity as shown in Progress page 2 of the FMC (Figure 16). The crew also checked the engines fuel consumption and the fuel quantity planned for the next waypoint and found it compatible with the flight plan. Following the checklist, the crew did not observe a fuel leak.

According the checklist, the crew attempted unsuccessfully, to balance between the L Main Tank and R Main Tank, while Center fuel Tank **Override/Jettison** pumps were operating, and therefore they returned the Boost pumps switches and the Crossfeed valve to their original position.

*Note 1: In the initial phase of the flight, the fuel to the engines is supplied from the Center Tank O/J pumps, until it is depleted and then the fuel supply to each engine is made from the Main Wing Tank Boost pump on its side.*

*Note 2: The checklist instructs to balance fuel between the Main wing Tanks, but such balancing is not feasible as long as the Center O/J pumps are running.*

After approx. 15 minutes, the crew tried again to perform the "Fuel Imbalance" checklist, in order to confirm they made no mistake on the first attempt, but failed again to balance the fuel in the Main Tanks, which led to their decision to return the switches to their original position, until the Center tank will get empty and balancing will be feasible.

*Note: The Center Tank was supposed to become empty following about 5.5 additional flight hours.*

Due to developed clouds on the route, the crew performed several route deviations of tens of miles. According to the crew, this deviation made it difficult to perform a simple and accurate cross checking of Planned vs. Actual fuel quantity, by flying over a planned waypoint and comparing Totalizer vs. calculated Planned quantity.

Approx. 2 hours and 10 minutes after takeoff, the relief flight crew entered the cockpit and was briefed by the outgoing crew about the "Fuel Imbalance" message. According to the outgoing crew's PIC, he briefed the incoming crew that the discrepancy can be dealt with, only after several hours, once the center tank will become empty. Shortly after the crew swap, the outgoing crew were recalled to the cockpit, due to a new EICAS message alert coming on: "Fuel Disagree".

According to the "Fuel Disagree" checklist, the crew checked the difference between the Totalizer and the Calculated fuel quantities, and found a difference of approx. 2,400 kg.

The crew conducted "Abeam" checks relating to the flight plan waypoints, and found that the Totalizer (actual) fuel quantity was lower by approx. 2,900 kg than the Calculated (anticipated) fuel quantity according to the flight plan.

The PIC returned to the captain's seat. A senior maintenance employee who occupy a managerial role at the company's MCC was on board, and also supported the aircraft dispatch from Bangkok. He was summoned by the crew to the cockpit. He was briefed about the situation, saw the fuel quantity differences and was requested to assist in identifying any possible leak, by executing a visual inspection of the wings.

Executing the "Fuel Disagree" checklist has guided the crew towards the "Fuel Leak" checklist, which instructs how to confirm and locate a potential fuel leak.

The "Fuel Leak" checklist requires visual inspection for a possible fuel leak from the wing and/or the engine. A mechanic and first officer were tasked with the visual inspection for a fuel leak. They visually inspected the "suspected" LH wing and engine. They were able to see the wing up to the engine's inboard side, but were unable to see the wing further down beyond the engine, due to the lighting conditions (darkness). They did not see any evidence of fuel leak or fuel spray.

<u>Note</u>: *Under the existing lighting conditions, and the location of the leak at the bottom tip of the right wing (Vent Scoop), the leak could not be seen.*

According to the "Fuel Leak" checklist, the crew shut down both Center Tank pumps and began monitoring any buildup difference between L and R Main Tanks. The checklist directs, that given a difference exceeding 500 kg within 30 minutes, this difference should be treated as a "fuel leak".

Within 20 minutes into the check, the crew observed a difference signs between the Main Tanks reaching 400 kg.

The crew said that after 20 minutes, there was a sharp change in trend, the gap between the Main Tanks (R Main Tank and L Main Tank) began to decrease, in contrast to the previous trend. The crew checked the fuel status display in the "fuel system Synoptic" and found that fuel was transferring from the Center Tank to the L Main Tank by means of the L Scavenge pump.

<u>Note</u>: *Review of the DFDR data showed that 400 Kg change in imbalance occurred **within 10 minutes** and that difference **remained unchanged for another 10 minutes** (total of 20 minutes).*

According to the crew's interviews, they came to the conclusion that without the fuel transferring from the Center Tank to the L Main Tank, using a Scavenge pump, the difference would have reached 500 kg within 30 minutes, which according to the checklist indicates a fuel leak on the left side (from the L Main Tank or L Engine).

The crew decided to divert to a nearby airport, Goa (GOI), located about 120 miles from their position at that time (Figure 2).

The crew continued to perform the "Fuel Leak" checklist. According to the checklist, the crew elected to refer to fuel quantity per the Totalizer, and modified the FMC fuel calculations accordingly.

The crew checked landing data for Goa airport: Single engine landing performance, flaps 20, anticipated landing weight upon arrival (exceeded max landing weight) and eventually determined that a safe landing can be performed.

*Note: The crew said that during the troubleshooting process they elected to refrain from communicating with El Al control (OCC), since they had a senior MCC representative on board. The crew updated OCC that they have shut down the engine and have decided to land at Goa airport.*

The crew shut down the LH engine as per the "Fuel Leak" checklist. The shutdown was executed at FL270 while descending to FL200 (2,000 feet below single engine cruise altitude as presented in the FMC) and the APU was activated. The crew declared emergency, called "MAYDAY" and requested direct radar guidance to GOI (Goa). Landing was conducted at a weight of 202 tons (approx. 10 tons above maximum landing weight).

Maximum automatic braking was utilized, the aircraft stopped slightly beyond the middle of the runway and the crew shutdown the other engine.

Upon the flight crew's request, the emergency ground crews cooled the wheels and brakes. The aircraft was towed to the parking ramp about an hour later.

The captain in command has been briefing the passengers throughout the event in flight and also informed them of the potential for vapor rising from the wheels during their cooling on the ground.

After parking, the passengers deplaned and were distributed to hotels.

A fault was recorded in the aircraft logbook, and instructions were written for downloading the data from the DFDR and CVR, in accordance with the operator procedures.

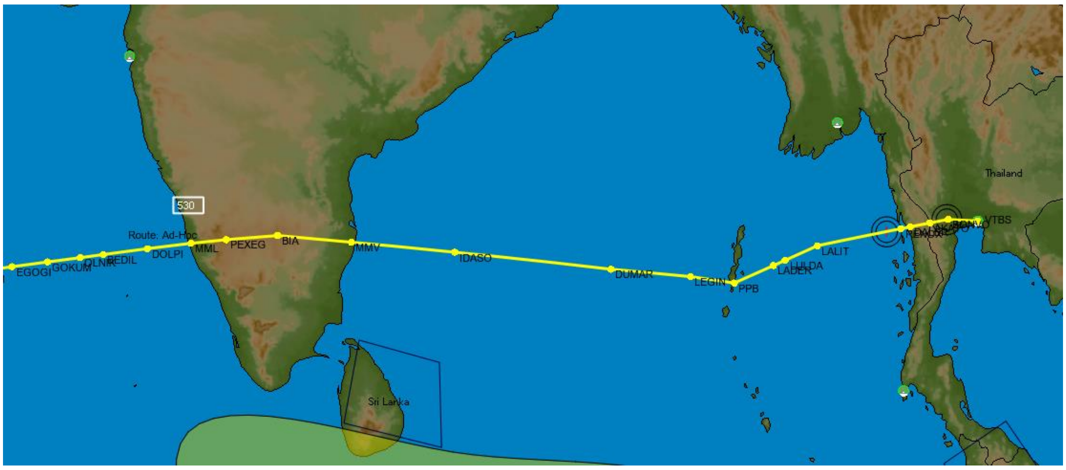


**Figure 1 - Scheduled flight route according to Flight Plan**

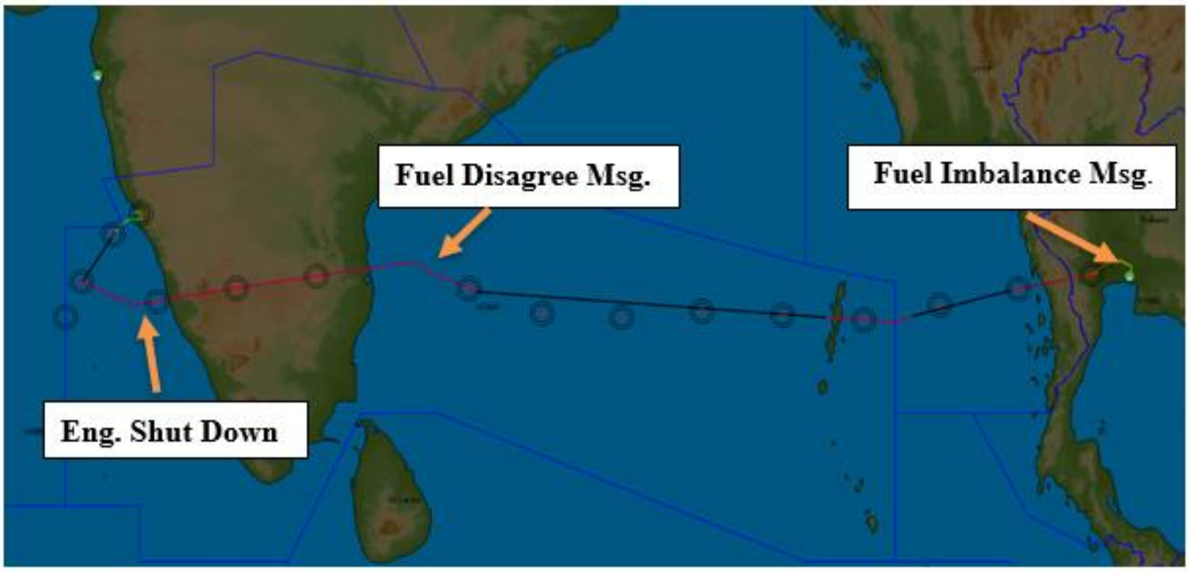


**Figure 2 - Actual flight route**

### 1.2 Injury to Occupants

| Injuries | Pilot | Passengers | Other |
|---|---|---|---|
| Death | | | |
| Severe | | | |
| Minor/None | | | |
| None | **None** | **None** | **None** |

### 1.3 Damage to aircraft - No damage

### 1.4 Other damage - No damages

### 1.5 Aircrew and other personnel involved

#### 1.5.1 Captain in command (PIC)

- ☒ Age: 63.
- ☒ Total flight hours: About 16,600 hours.
- ☒ Total flight hours on type: 1,380 hours.
- ☒ Last proficiency check on type: May 2, 2021.
- ☒ Medical certificate valid until: March 20, 2022.

#### 1.5.2 Relief Captain (became active 2:15 hours after takeoff)

- ☒ Age: 57.
- ☒ Total flight hours: About 20,600 hours.
- ☒ Total flight hours on type: 1,611 hours.
- ☒ Last proficiency check on type: May 4, 2021.
- ☒ Medical certificate valid until: September 8, 2022.

### 1.5.3 First officer (served as PM)

- Age: 63.
- Total flight hours: About 11,400 hours.
- Total flight hours on type: 750 hours.
- Last proficiency check on type: October 4, 2021.
- Medical certificate valid until: April 13, 2022.

### 1.5.4 Relief first officer (became active 2:15 hours after takeoff)

- Age: 56.
- Total flight hours: About 11,300 hours.
- Total flight hours on type: 1,031 hours.
- Last proficiency check on type: June 12, 2021.
- Medical certificate valid until: June 3, 2022.

## 1.6 Aircraft information

### 1.6.1 General information

- Model: B787-9.
- Manufacturer: Boeing Company.
- Serial Number: 63548.
- Year of Manufacture: 2017.
- Line Number: 590.
- Nationality: Israel.
- Registration: 4X-EDA.
- Certificate of registration validity: Aug 15, 2022.
- Owners: ALC B7879 63548, LLC.
- Operator: El Al Israel Airlines Ltd. ("The company").
- Certificate of airworthiness validity: Aug 15, 2022

### 1.6.2 Aircraft history

- Total flight hours: 13,826.
- Total flight cycles: 1,602.

### 1.6.3 Engines

- Manufacturer: Rolls Royce.
- Model: Trent 1000-J3.
- Serial numbers: LH – 11129, RH – 11059.
- Last inspection: LH – March 22, 2020, RH – November 23, 2019.
- Both engines operated properly throughout the flight (until intentional shutdown of LH engine).

### 1.6.4 Fuel

- ☒ Approved type: Jet-A1.
- ☒ Type refueled: Jet-A1.
- ☒ Quantity refueled: 75,231 liter (59,207 kg).
- ☒ Total quantity in tanks after refueling: 64,700 kg.
  (LH tank – 16,400 kg, RH tank – 16,400 kg, center tank – 31,900 kg).
- ☒ Total fuel required according to the flight plan: 62,932 kg.
- ☒ Fuel quantities, (automatic) activation of pumps, valves, etc., are performed in the aircraft according to **fuel volume** (not fuel weight). For the reader's convenience and understanding, fuel data in the report are presented in approximate **weights** (which vary depending on fuel density), as presented during the event itself.

### 1.6.5 Aircraft maintenance

- ☒ The aircraft was maintained at the company's maintenance facility in accordance with Boeing's instructions and at the required time frames.
- ☒ Last "heavy" maintenance – C-Check, conducted on January 17, 2020 at El Al's maintenance facility. Last A-Check was performed on September 9, 2021.
- ☒ No special maintenance activities related to the fuel system have been conducted.

### 1.6.6 Aircraft instruments

- ☒ There were no findings indicating any deficiency of the aircraft instruments.
- ☒ Fuel measurement variations were reported, mainly related to pitch attitude changes in climb/descent, as well as at ground taxiing. It was manifested in fluctuations of the indicated fuel quantity (Totalizer), which typically happen on every flight (per the FCOM).

### 1.6.7 Transmittal of technical status from aircraft to ground station

- ☒ In checking with OCC representative, it turned out that the aircraft transmitted regularly at 15 minutes intervals, but the "Flight Watch" system, which compares the fuel quantity transmitted from the aircraft to the flight plan has not detected a fuel problem.
- ☒ In checking with MCC representatives, it turned out that once in a while the aircraft transmitted messages regarding various discrepancies, but no transmission was received regarding EICAS advisory messages of "Fuel Imbalance" or "Fuel Disagree".

### 1.6.8 Fuel data throughout the flight

The following table presents the fuel consumption and fuel transfers between the tanks throughout the flight as well as the relevant flight events (source: **DFDR recording**).

| UTC (31-Oct-2021) | Event | Alt. (Ft) | Fuel (Kg) | | | | | Diff. TOT Vs. CAL |
|---|---|---|---|---|---|---|---|---|
| | | | L Main | Center | R main | TOT | CALC | |
| 18:14:00 | End of Aircraft Refueling | 45 | **16,400** | 31,900 | **16,400** | 64,700 | | |
| 18:55:32 | Taxi Out | 45 | **16,200** | 31,900 | 16,400 | 64,500 | 64,500 | 0 |
| 19:06:15 | End of Taxi | 45 | 16,400 | 31,900 | **16,700** | 65,000 | 64,300 | 700 |
| **19:08:05** | **Takeoff** | 51 | 16,400 | 31,800 | 16,700 | 64,900 | 64,004 | 896 |
| 19:13:37 | **Fuel Imbalance Message** | 9,200 | **16,200** | 29,600 | 16,700 | 62,500 | 62,641 | -141 |
| 19:17:53 | Climb **(Fuel leak started)** | 15,500 | 16,200 | 28,900 | 16,800 | 61,900 | 61,818 | 82 |
| 19:20:58 | Crossfeed 1 (9min 20sec duration) | 19,030 | 16,200 | 28,300 | 16,800 | 61,300 | 61,328 | -28 |
| 19:34:52 | Crossfeed 2 (3min 48sec duration) | 29,210 | 16,200 | 25,800 | 16,800 | 58,800 | 59,239 | -439 |
| 20:25:36 | Crossfeed 3 (7min 10sec duration) | 34,000 | 16,200 | 19,500 | 16,800 | 52,500 | 53,717 | -1,217 |
| 21:41:28 | **Fuel Disagree Message** | 34,000 | 16,100 | 10,700 | 16,900 | 43,700 | 46,111 | **-2,411** |
| **Fuel Leak Check Section** | | | | | | | | |
| 22:06:09 | Center O/J Pumps OFF | 34,000 | 16,100 | 7,700 | 16,900 | 40,700 | 43,640 | **-2,940** |
| 22:08:09 | Fuel Leak Check Start | 34,000 | 16,000 | 7,600 | 16,900 | 40,500 | 43,405 | -2,905 |
| 22:16:43 | Fuel Recapture (Surge Tank to Main Tank) Complete | 34,000 | 15,600 | 7,600 | 16,900 | 40,100 | 42,575 | -2,475 |
| 22:26:41 | Scavenge Activation / Fuel Leak Check End | 34,000 | 15,200 | 7,500 | 16,400 | 39,100 | 41,600 | -2,500 |
| 22:43:57 | **L Engine Shutdown** | 27,200 | 15,500 | 6,600 | 15,700 | 37,800 | 40,365 | -2,565 |
| 22:54:40 | **Fuel Imbalance Message** | 12,200 | 16,100 | 6,000 | 15,500 | 37,600 | 40,206 | -2,606 |
| **23:13:04** | Landing | 231 | 16,400 | 5,200 | 15,100 | 36,700 | 39,337 | -2,637 |

**Table 1 - Fuel quantities in the tanks**

*Notes (according to UTC times):*

- *At end of refueling, fuel quantities in both wing tanks were **equal**, 16,400 kg in each (18:14).*
- *At taxi out, LH tank quantity decreased by 200 kg due to APU consumption (18:55).*
- *At end of taxi and line up for takeoff, LH tank fuel quantity was 16,400 kg, RH tank 16,700 kg (19:06).*
- *During taxi and takeoff, fuel quantities in each Main Tank are not displayed to the crew (only the total fuel quantity), (See Figures 13, 14).*
- *Minor errors in fuel quantity indications might occur during taxi, takeoff and climb due to fuel sloshing in the tanks.*
- *Regarding the column Diff. Tot Vs. Cal, it should be noted that some differences may be attributed to fuel sloshing or shifting, particularly during takeoff and climb.*
- *Upon the illumination of "Fuel Imbalance" message (about 6 minutes after takeoff), LH tank fuel quantity was 16,200 kg and RH quantity was 16,700 kg. Difference between wings' quantities was approximately 500 kg (19:13).*
  *(Note: These figures will be explained below).*
- *Upon crossing altitude of 15,500 feet (as a control point), LH tank fuel quantity remained at 16,200 kg, while RH quantity increased to 16,800 kg. (19:17).*
- *Upon the illumination of "Fuel Disagree" message (at cruise, approximately 2.5 hours after takeoff), LH tank fuel quantity was 16,100 kg and RH quantity was 16,900 kg (21:41).*
- *Upon shut down of the center O/J pumps, fuel quantity showed no change from the time "Fuel Disagree" message illuminated (LH tank 16,100 kg and RH tank 16,900 kg) (22:06).*
- *For a period of about 11 minutes, the RH tank fuel quantity remained unchanged at 16,900 kg, despite fuel consumption by the engine, while LH tank quantity was decreasing gradually according to the engine's consumption rate, about 40 kg/minute (22:17). (Note: See explanation below for the RH fuel quantity not decreasing).*
- *LH tank fuel quantity stopped decreasing and subsequently began to increase at (22:25).*
  *(Note: See explanation below).*

### 1.6.9 Scavenge pumps

The Scavenge pumps are located in the Center Tank. Their role is to transfer fuel from the Center Tank to the main wing tanks when there is fuel in the Center Tank and the Center pumps are turned OFF. Each pump can transfer fuel to the Main Tank on the same side.

When there is fuel in Center Tank, both center pumps are turned OFF and at least one wing tank Boost pump is operating, the Scavenge pump is automatically activated when wing tank quantity (on its side) is decreasing below about 15,500 kg and is stopped (automatically) when the Main tank fuel quantity is full (about 16,700 kg). The Scavenge pump activation and deactivation depend on several parameters, including fuel density.

Below is what is written in FCOM:

The fuel scavenge system starts when either main fuel tank (LH and/or RH) decreasing beyond approximately 34,100 lbs (15,500 kg), which corresponds to approximately 7% empty space, by volume (FCOM).

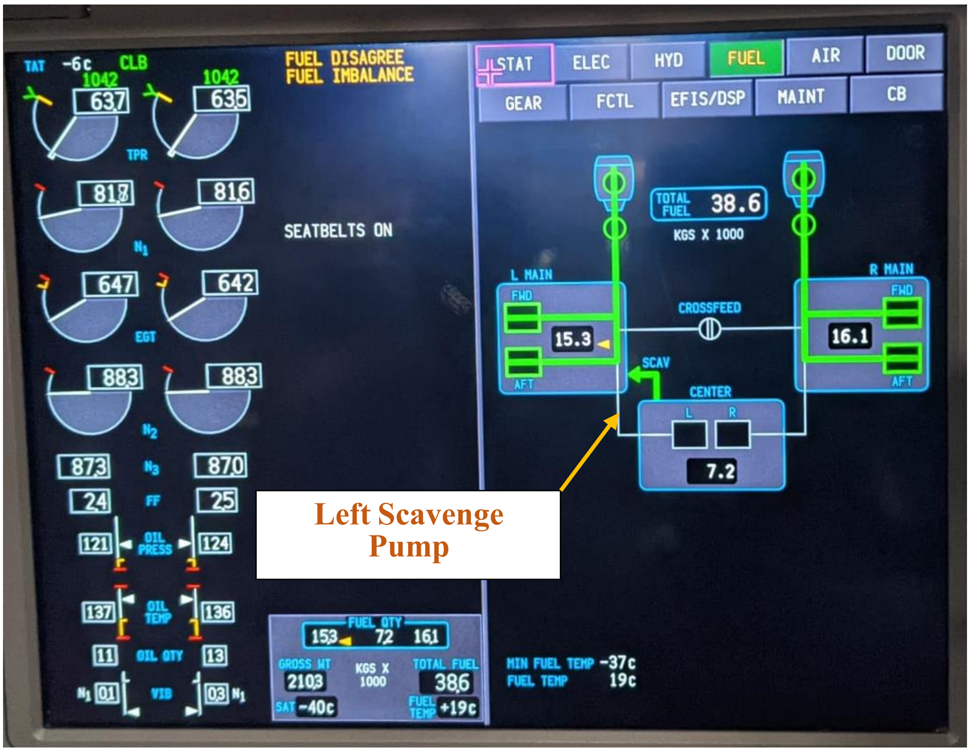


**Figure 3 - "SYNOPTIC" display after turning off CENTER pumps and activation of the scavenge pump**

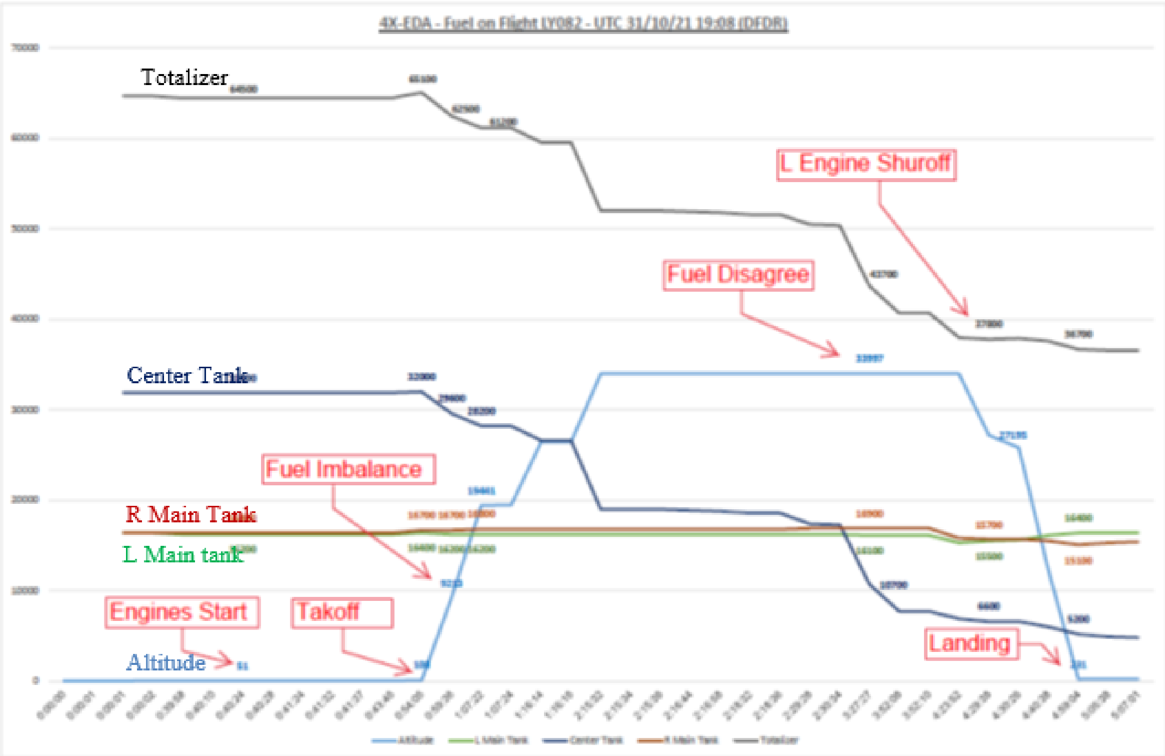


**Figure 4 - Flight sequence of events and fuel chart**

(Time history from recorded data)

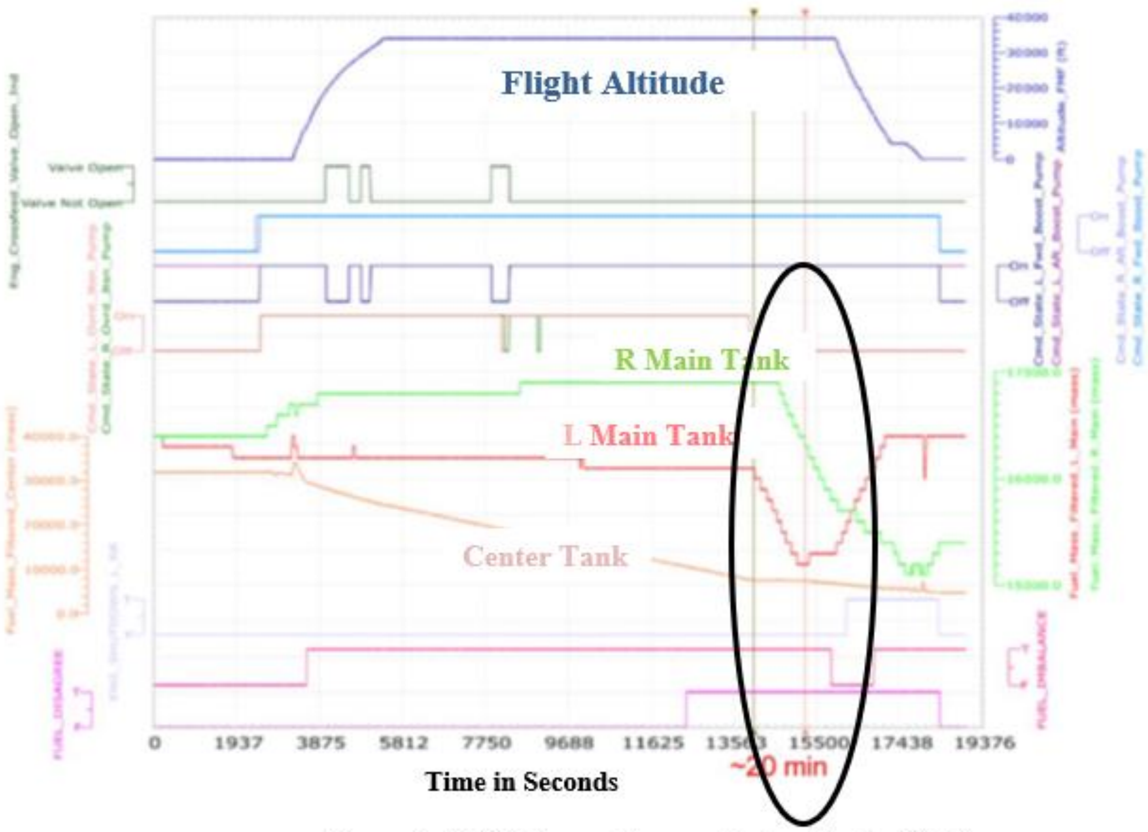


**Figure 5 - DFDR recording analysis - Fuel in flight**

*<u>Note</u>: The marked time frame (20 min) is the stage where "Fuel Disagree" message was on and the center pumps were <u>turned off</u> (fuel quantity in the center tank remained constant). It can be seen that RH wing fuel quantity remained unchanged for about 11 minutes (despite its fuel being consumed by the engine), while LH wing fuel quantity starts decreasing immediately.*

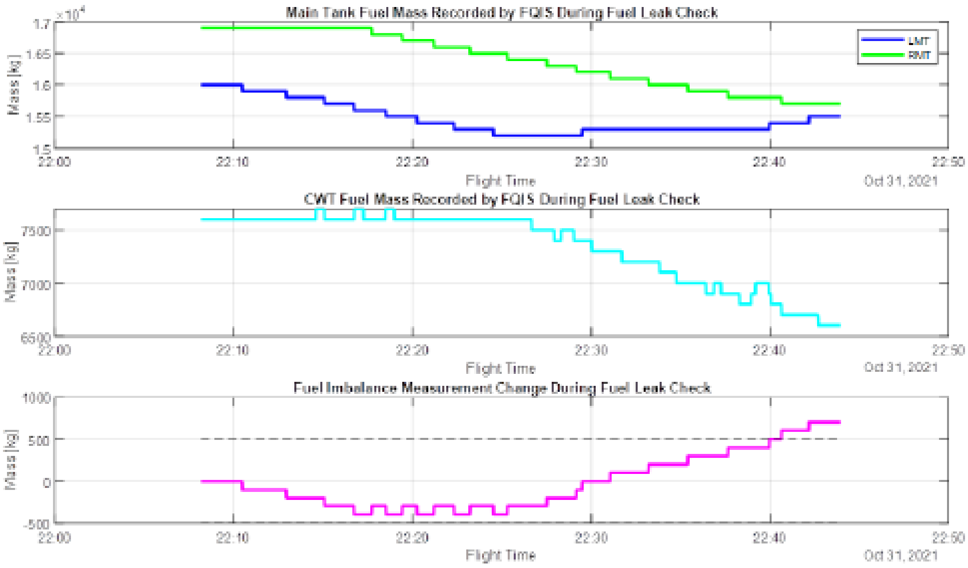


**Figure 5 - DFDR analysis of fuel behavior during performance of Fuel Leak checklist**

### 1.6.10 Aircraft weight and balance

The various aircraft weights [kg] (planned and actual):

| # | | DOW | Payload | ZFW | Fuel | TOW |
|---|---|---|---|---|---|---|
| 1 | Flight Plan | 129,329 | 40,271 | 169,600 | 62,932 | 232,132 |
| 2 | Actual (Load Sheet) | 129,329 | 42,371 | 171,700 | 64,500 | 235,800 |

**Table 2 - Weight and balance**

The table indicates that the aircraft was loaded by 2.1 tons heavier than the original planning of the flight plan. According to the crew, they determined that the additional 1.5 tons of fuel, which were refueled in order to allow for detours around areas of turbulent weather, will also suffice for the added weight of the cargo.

*Note: This issue was checked. A revised flight plan was prepared with the actual weights per the load sheet. The revised plan resulted in a requirement for approx. 700 kg. Hence the added fuel of about 1,500 kg was sufficient for both the added weight and the weather detours.*

## 1.7 Goa weather (VOGO/GOI)

**FT**

311500 3118/0124 01005KT 6000 FEW020 SCT090TEMPO 3123/0102 3000 BR BECMG 0105/0107 09010 KT 6000 BECMG 0110/0112 32008 KT TEMPO 0116/0118 05006KT 5000 BR/DZ

**SA**

METAR VOGO 312300Z 04004KT 6000 FEW016 BKN080 26/24 Q1009 NOSIG

## 1.8 Radio navigation aids – Not applicable.

## 1.9 Communication

The diversion was performed while under Chennai Control.

SATCOM and CPDLC communications were automatically transmitted during the flight and El Al OCC received aircraft data in 15 minutes intervals. Data included: Geographic coordinates, altitude, Calculated fuel quantity. Additionally, El Al MCC received technical data by means of Aircraft Health Management system (AHM), which included various warnings and discrepancies, whenever such have occurred.

## 1.10 Goa airport information (GOI)

- Airport designation: IATA – GOI, ICAO – VOGO.
- Coordinates: 73°49’40.17”E, 15°22’47.42”N.
- Field elevation: 180 feet.
- Number of runways: 1.
- Runway length: 11,240 feet (3,426 meters).
- Runway width: 148 feet (45 meters).
- Type: Asphalt.
- Runway headings: 08/26.
- Taxiways' width: N1, N2 – 22.5 meters, S1, S2 – 25 meters.
- Aircraft suitability: Suitable for landing of wide body airliners, up to and including B747-400.
- Emergency services: Firefighting and rescue equipment CAT VIII.

## 1.11 Flight recording data

- EAFR manufacturer: Rockwell Collins.
- Model: EAFR-2100 (Enhanced Airborne Flight Recorder), combined FDR and CVR.
- Number of recorded parameters: about 2700.
- Recording format: Digital.
- Condition of units: Adequate.
- CVR recording duration: **2 hours**.

- The aircraft has 2 recording units (EAFR-2100) installed one at the front near the L1 door and the other at the rear near the L4 door.
  *<u>Note</u>: each EAFR includes both DFDR and CVR.*
- The MEL allows dispatch with one operative EAFR.
- DFDR data were forwarded by the Chief Investigator Office to the NTSB for analysis.
  - ✓ There were findings of fuel transfer from center tank to RH wing (R Main Tank).
  - ✓ It was found that approx. 2.9 tons of fuel were spilled out through the right wing during the flight.
- After landing at Goa, on 1.11.2021, a logbook entry no. 10286659 was created (by the PIC), to download the DFDR and CVR data (per the company's procedures), in order to retrieve the data for safety investigation. This procedure is mandatory per the company procedures OM-A 1.4.3, OM-A 11.4.2, AIPM 9-4, DMC-B787-A-31-31-01-01A-520A-A and GMM 31-31-00-00 (see Appendix 5).
  The DFDR data were downloaded, but the CVR data was not downloaded since the company does not have suitable equipment. According to the company procedures, the FWD EAFR should have been disconnected from power to preserve the stored data (by opening the relevant CB). But during the engines runups the FWD EAFR was connected to power which led the relevant CVR data to this incident to be erased.
  On 8.11.2021, a logbook entry no. 10286673 was created by a technician and the EAFR CB was opened, but at this stage **all CVR data from the event flight were already erased**.
- The investigation team checked whether there was a need to connect the recorders for engines runup, according to maintenance procedure DCM-B787-A-R71-00-00-09A-110A-A for engines runup. It was found that there is no requirement to have both EAFRs connected during the runup.
- DFDR data were downloaded to a maintenance computer, which was shipped to Israel on a special flight who arrived at Goa to pick the passengers and crew.
- Procedure for preserving data in case of aircraft accident/incident - See Appendix 5.

### 1.12 Aircraft wreckage and ground impact data – Not applicable.

### 1.13 Medical and pathological information – Not applicable.

### 1.14 Fire – Not applicable.

### 1.15 Survival aspects – Not applicable.

## 1.16 Examinations and research

1.16.1 Three similar cases occurred in other airlines, identified as "inadvertent transfer of fuel between the aircraft tanks" were examined.

1.16.2 A similar fuel leak case on Air India's B787-8, India's registration VN-ANE, at Mumbai airport on August 21, 2017, was published in investigation report No. AV.15017/76/2017-AS, issued by the Aircraft Accident Investigation Bureau (AAIB) of India's Ministry of Civil Aviation. In the subject event, a 787-8 aircraft on night flight AI-131 from Mumbai to London was refueled with 52,600 kg of fuel (16,600 kg in each main tank and 19,400 kg in center tank). The aircraft was pushed back and upon engines start fuel quantity was 52,400 kg. It began taxiing for takeoff, while after 2 minutes the "Fuel Imbalance" message came on.

The crew performed the checklist and continued the taxi. An Oman Air aircraft taxiing behind the Air India aircraft reported a fuel leak from the RH wingtip. The ground controller directed the Air India aircraft to stop taxiing and dispatched rescue and firefighting teams rushed towards the aircraft.

At that stage, the flight crew noticed that about 1,000 kg fuel were missing and decided to return to the parking gate. The aircraft was routed to another taxiway, where the engines were shut down and the APU was started.

The firefighting team confirmed that the leak has stopped following engines shutdown, with only minor dripping of fuel. The aircraft was towed to a parking spot, while a team of technicians has arrived and saw indications of fuel leak from the Vent Scoop of the RH wing Surge Tank (from the drain port). The EICAS "Fuel Imbalance" message was still ON. Fuel status: Total quantity in tanks 50,100 kg, **L Main Tank 16,200 kg, R Main Tank 17,200 kg,** Center tank 16,700 kg. The RCP was checked and found that the red Overfill light is blinking. No evidence of fuel leak from the RH wing has been found. The Surge Tank was drained and the RCP Overfill light was reset. A normal Fuel balance was performed and all valves functioned as required. The aircraft was towed to the hangar for continued troubleshooting:

- ✓ Fuel transfer from center tank to R Main Tank (RH wing) stopped automatically at 16,700 kg - found normal.
- ✓ Operated Override/Jettison pumps and opened Crossfeed valve, once with refuel/defuel valve open and once with it closed, while verifying that main tanks fuel quantity is not changing - found normal.
- ✓ Engines runup at idle thrust, with open Crossfeed valve - No change in main tanks fuel quantity was noted.
- ✓ Defueling check - found normal.

- ✓ The actuator of the RH inboard refueling valve was replaced as a precautionary step. All tests were subsequently conducted with no anomalies. The valve was inspected at a service center and found serviceable.
- ✓ Boeing's company assumption and conclusion attributed for a FOD, and recommended checking the RH engine's fuel filter. The filter was inspected and found adequate.
- ✓ The aircraft was released for flights and the discrepancy did not reoccur.

1.16.3 Another case examined was a fuel leak on a fairly new B787-8 of JAL company, flight JL007 from Boston to Tokyo on January 8, 2013. A fuel leak from the LH wingtip was noticed during taxi and the aircraft was returned to the gate. Inspection found a seal jammed in one of the valves, which caused transfer of fuel from the center tank to the L Main Tank and from it to the L Surge Tank. About 120 kg of fuel spilled overboard.

On the same airplane, on Jan 13, 2013, another case of fuel leak was detected at Tokyo airport. Investigation discovered FOD event during aircraft manufacturing - remains of a seal in the tank. Paint residues were found on the solenoid of one of the refuel check valves, which caused the valve to jam in mid travel (half open). Components were replaced and the discrepancy did not reoccur.

1.16.4 Another case of fuel leak was reported on a Norwegian Air Shuttle B787-8, flight from Bangkok to Oslo on January 19, 2014. Fuel leak from the RH wing vent scoop was noticed during taxiing. The aircraft returned to the gate for troubleshooting and takeoff was delayed by 19 hours.

**Figure 6 - Air Norwegian Shuttle fuel leak**

*<u>Note</u>: It can be seen that the leak source is the wing tip vent scoop*

## 1.17 Information regarding organization, company management and regulator

- ☒ The operator - El Al company, an old airline, has been active since 1948, with a fleet of 45 aircraft, including: 737-800 aircraft - 16, 737-900 - 8, 777-200 - 6, 787-8 - 3, 787-9 - 12. The company operates the model involved in the incident since August 2017.
- ☒ Maintenance facilities - The aircraft was being maintained at El Al maintenance facility.
- ☒ Air traffic control units - Not applicable.
- ☒ Aircraft manufacturer - The Boeing company, USA, which is manufacturing 3 variants of the 787 (787-8, 787-9, 787-10) and has delivered more than 1000 aircraft.
- ☒ Certificating authorities - The aircraft has FAA Type Certificate T00021SE and CAAI Type Certificate IA303.
- ☒ Civil Aviation Authority Israel - CAAI is conducting certification, supervision and enforcement over the operator.

## 1.18 Additional relevant information

### 1.18.1 General information

- ☒ During the investigation, the Manufacturer sent information that the fuel Crossfeed valve position is monitored by the DFDR. The parameters are "Eng_Crossfeed_Valve_Open_Ind" and "Eng_Crossfeed_Valve_Close_Ind".
- ☒ Neither the DFDR nor FOQA are monitoring the status of the Scavenge pumps in the Center fuel tank.
- ☒ There is no indication for the fuel amount in the Surge Tank.
- ☒ Data recorded on the DFDR, FOQA and FMF was analyzed in order to obtain an accurate depiction of the fuel "behavior" in the flight.
- ☒ According to new EASA regulation, EUROCAE Document ED-112A, and according to regulation 965/2012, as of January 1, 2021, installation of a CVR capable of recording **over 25 hours** is mandatory for any new aircraft with a takeoff weight exceeding 27 tons. CVRs capable of 25 hours recording are currently available on the market for various aircraft models, including Boeing B737, B777, B787 and Airbus A320, A321.

1.18.2 Manuals used by the operator

**Company OM-A:**

The operator's OM-A was accepted by CAAI on May 10, 2021:

"The CAAI has "accepted" the **O**perations **M**anual, and receives all amendments and revisions thereto. Paragraphs notated "**APPROVED**" within this manual are approved by the CAAI".

The Operator OM-A paragraph 8.3.20.1 states:

General Operating Procedures

"All aircraft shall be operated according to the SOP, operating limitations and operating procedures as described in the OM Part B - Boeing documentation (**FCOM**, **FCTM**) as modified by EL AL to reflect the Company's safety policy".

1.18.3 **The Introduction in the manufacturer's (Boeing) explanation for using the NNC includes the following topics (Bold letters below were not bold in the original text):**

787 Flight Crew Operations Manual

| Checklist Instructions | Chapter CI |
|---|---|
| Non-Normal Checklists | Section 2 |

**Introduction**

- All checklists have condition statements. The condition statement briefly describes the situation that caused the EICAS alert message. Un-annunciated checklists also have condition statements to help in **understanding the reason for the checklist.**
- While every attempt is made to supply needed non–normal checklists, **it is not possible to develop checklists for all conceivable situations.**
- **Usually, time is available to assess the situation before corrective action is started.**
- **In all situations**, the captain **assesses the situation** and uses **good judgment to determine the safest course of action.**
- some situations, **at the captain's discretion, deviation from a checklist may be needed.**

1.18.4 **The operator's manual (El Al company), according to the SOP specified in the FCTM:**

**Non-Normal Operations**

**EL AL אל על**

**777/787 Flight Crew Training Manual**

FCTM paragraph 8.1 includes the following topics:

**Non-Normal Situation Guidelines**

**ANALYZE THE SITUATION**: NNCs should be accomplished **only after** the malfunctioning system has been **positively identified**. Review all EICAS messages to positively identify the malfunction system(s).

**Troubleshooting**

Troubleshooting can be defined as:

- taking steps beyond a published NNC in an effort to improve or correct a non-normal condition.

Later on, it states:

The crew should consider additional actions beyond the checklist only when completion of the published checklist steps clearly results in an unacceptable situation.

**Detection of Flight Crew Alerts**

In all situations, the flight crew should review all flight deck alerts and **analyze the situation** in order to determine the **appropriate course of action**.

Additionally, FCTM paragraph 8.4 states:

**"Human Performance under High Stress and Workload**

…Crews rarely, if ever, face a situation in the simulator for which there is no checklist or procedure, even though this can be the case in actual emergencies. Additionally, crews do not typically encounter a simulated event for which the checklist procedures do not work as expected....

It is, of course, impossible to develop procedures and checklists for every possible situation…"

FCTM paragraph 1.2 refers to the SYNOPTICS:

System synoptics are simple schematics representative of airplane system operation and are supplemental information only.

(See detailed explanation in Appendix 7).

1.18.5 **The Israeli Aviation Law 2011, paragraph 76 (b)(1) states:**

"In case of an emergency, which, in the opinion of the pilot in-command, requires immediate action for protecting human life or maintaining the safety as stated in subsection (a), **he may deviate from the provisions of any law regarding the operation of the aircraft, as necessary under the circumstances;**".

1.18.6 **In-flight fuel consumption procedure, as per OM-A paragraph 8.3.8:**

Policy and Procedures for In-Flight Fuel Management;

The fuel situation shall be continually monitored by the flight crew. The PIC shall ensure that fuel checks are recorded at least every hour during a flight. On a flight of less than one hour an intermediate record is to be made at a convenient time when the cockpit workload permits.

The relevant fuel data shall be recorded on the operational flight plan and evaluated to:

- Compare actual consumption with planned consumption;
- Check that the usable remaining fuel is sufficient to complete the flight, in accordance with the requirements below; and
- Determine the expected usable fuel remaining on arrival at the destination airport.

OM-A paragraph 8.3.20 states:

Flight crew members shall check and record in the OFP the fuel status and time over waypoints at least once every 60 minutes to ensure that minimum fuel upon landing will be greater than the final reserve fuel. See also Chapter 8.1.9 "Operational Flight Plan (OFP) and Flight Release".

1.18.7 **In Accordance with the Israeli Aviation Regulations, operations regulations paragraph 480 b.(a):**

"The pilot in-command will verify for the duration of the flight that the available amount of fuel -

(1) that remains in the aircraft tanks is not less than the amount of fuel required to proceed to an airport where a safe landing can be made, and to land there when the aircraft has a final reserve amount of fuel;

(2) which is expected to remain in the aircraft fuel tanks upon arrival at the destination field, shall not be less than the amount of fuel required for a flight to a an alternate (Destination alternate fuel) as specified in Regulation 522(C)(4)(A) to (D), as applicable, and additional reserve fuel suffix."

<u>Note</u>: In any case of abstruseness or misunderstanding, the original Israeli Aviation Regulations in the Hebrew language is prevail.

1.18.8 **Manufacturer (Boeing) reference to FAA documents for definitions of terms**:

The manufacturer (Boeing) updated the NNC "Introduction" section, including an additional paragraph titled **Analyze the Situation** (see Appendix 4).

For purpose of clarifying the above term, the manufacturer (Boeing) refers to the FAA documents which clarify the term: **Analyzing and positive identification.**

The definition for the terms **Analyzing** and **Positive Identification** by the FAA is shown in the following documents.

In general terms of intent of "analyzing" and "positive identification" of an issue by the flight crew, Boeing would point to FAA Advisory Circular AC 60-22 and the FAA Pilot's Handbook of Aeronautical Knowledge FAA-H-8083-25 Chapter 2 for expectations related to Aeronautical Decision Making (ADM).

The **FAA** definition for the term **Analysis** from the following documents:

**FAA-H-8083-25** Page 2-20,

***Detect (the Problem)***

Problem detection is the first step in the decision-making process. It begins with **recognizing a change occurred or an expected change did not occur**. A problem is perceived first by the senses and then it is distinguished through insight and experience. These same abilities, as well as **an objective analysis of all available information, are used to determine the nature and severity of the problem**. One critical error made during the decision-making process is incorrectly detecting the problem.

***Choose (a Course of Action)***

After the problem has been identified and its impact estimated, **the pilot must determine the desirable outcome and choose a course of action**.

***Identify (Solutions)***

The pilot formulates a plan that will take him or her to the objective. Sometimes, there may be only one course of action available. In the case of the engine failure already at 500 feet or below, the pilot solves the problem by identifying one or more solutions that lead to a successful outcome**. It is important for the pilot not to become fixated on the process to the exclusion of making a decision.**

*Do (the Necessary Actions)*

Once pathways to resolution are identified, **the pilot selects the most suitable one for the situation**. The multiengine pilot given the simulated failed engine must now safely land the aircraft.

*Evaluate (the Effect of the Action)*

**Finally, after implementing a solution, evaluate the decision to see if it was correct. If the action taken does not provide the desired results, the process may have to be repeated.**

1.18.9 In the OM-A paragraph 8.3.20.1, a systematic event management method is specified by means of "FORDEC", which is practiced and implemented by the operator.

"**FORDEC**" - **F**acts, **O**ptions, **R**isks and benefits, **D**ecision, **E**xecution, **C**heck and recheck.

The "FORDEC" is executed after the fault has been dealt with (completion of the checklist).

1.18.10 The fuel system

**System description**

The fuel system consists of two Main Tanks located in the wings and a Center Tank (body) with a total volume of 33,380 USG (approximately 101,084 kg). Each Main tank 5,520 USG (approximately 16,716 kg), and a Center tank 22,340 USG (approximately 67,652 The amount of fuel varies according to the specific gravity of the fuel (depending on temperature, air density, etc.), and is the one shown to the pilot in the aircraft's instruments.

Note: *The volume of the tanks is fixed, but the weight of the fuel varies according to its specific weight.* ***In the report, for the sake of convenience, all dimensions in kg will be indicated***.

Fuel quantity varies with the fuel specific weight (depending on temperature, air density, etc.).

There is a "Surge Tank" at each wingtip, beyond each side of Main fuel tank. Its capacity is about 481 kg (160 USG) and its role is to accommodate fuel surplus, in case the Main Tank is filled beyond its maximum capacity. When the Main Tanks begins to be supply fuel to the engine, fuel is returned from the Surge Tank to the Main Tank. The Main Tank Vent line is drained into the Surge Tank. When fuel in the Surge Tank exceeds its capacity, fuel will be spilling overboard via the Vent Scoop at the wingtip area.

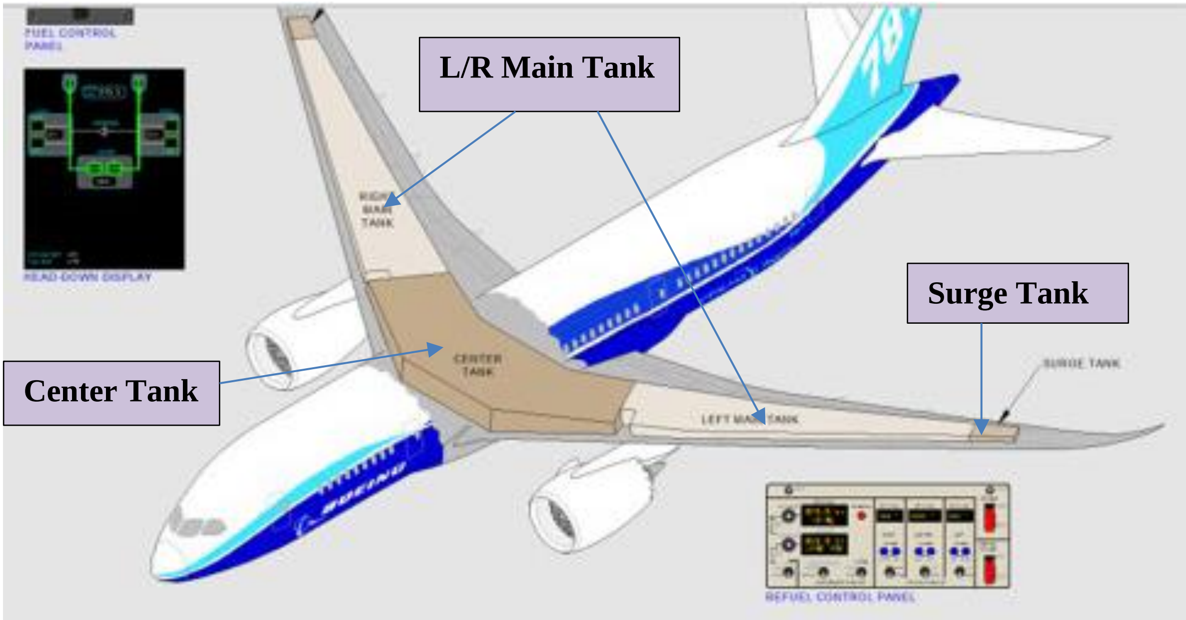


**Figure 7 - B787-9 Aircraft Fuel Tanks**

Each Main Fuel Tank has 2 Boost pumps and the Center Tank has 2 Override/Jettison pumps. Center Fuel Tank pumps deliver higher pressure than Main fuel Tank Boost pumps. The pumps deliver fuel to the engines via a shutoff valve.

Additionally, there are 4 Scavenge pumps (one in each Main Tank and two in Center Tank). In the Main Tanks these are Water Scavenge pumps, which pump water and fuel from the bottom of the tank and feed them into the Boost pumps (The water mix with fuel and are evaporated in the engine's combustion process). In the Center Tank there are 2 Scavenge pumps that are designed to pump fuel from the fuselage (Center) tank and transfer it to the Main Tanks, in case the Override/Jettison pumps are not operating and there is still fuel in the Center Tank.

The Scavenge pump, is activated automatically when the fuel level in the Main Tank drops below approx. 15,500 kg on its side (right or left), and stops working automatically, when the fuel level in the Main Tank rises, and reaches a full tank (approx. 16,700 kg).

Refueling is conducted by means of Refuel Control Panel (RCP) at the bottom of the LH wing, which enables ground refueling at a pressure up to 55 psi within 45 minutes up to full tanks. The RCP can also be used for defueling the aircraft. Fuel pipes are routed from the RCP to all tanks. These pipes are also used by the jettison system. In each Main Tank and in Center Tank there are 2 refuel/defuel valves.

The aircraft has an inflight fuel Jettison system, in order to enable fast fuel dumping for reaching the desired landing weight.

A Vent piping system maintains tanks pressure balance and drains excess fuel to the wingtip Surge Tanks. Check valves enable flow of fuel from the Surge Tank back to the L or R Main Tank.

APU fuel is supplied from the left fuel manifold. APU fuel can be provided by any AC fuel pump (Boost pump) supplying fuel to the left fuel manifold, or by the left Main Tank DC fuel pump.

A Nitrogen Generation System (**NGS**) is aimed at preventing explosive atmosphere in the fuel tanks, by supplying Nitrogen to fill the volume vacated by the consumed fuel and thus create an inert atmosphere.

A Fuel Quantity Indicating System (**FQIS**) is measuring the fuel levels in the tanks, calculates and displays the fuel weight and provides the data to the Fuel Quantity Management System (**FQMS**). The FQIS has 2 separate, independent channels of sensors.

The FQMS manages the fuel in flight and sends fuel data to the Flight Management Computer (FMC).

**Surge Tank** - Drains excess fuel from the Main Tank and returns fuel to the Main Tank when the Main Tank begins to supply fuel to the engine. The Surge Tank can hold approximate excess of 480 kg (160 USG) of fuel before spillage overboard. However, fuel may be spilled at lower volumes, due to maneuvers and attitude angles.

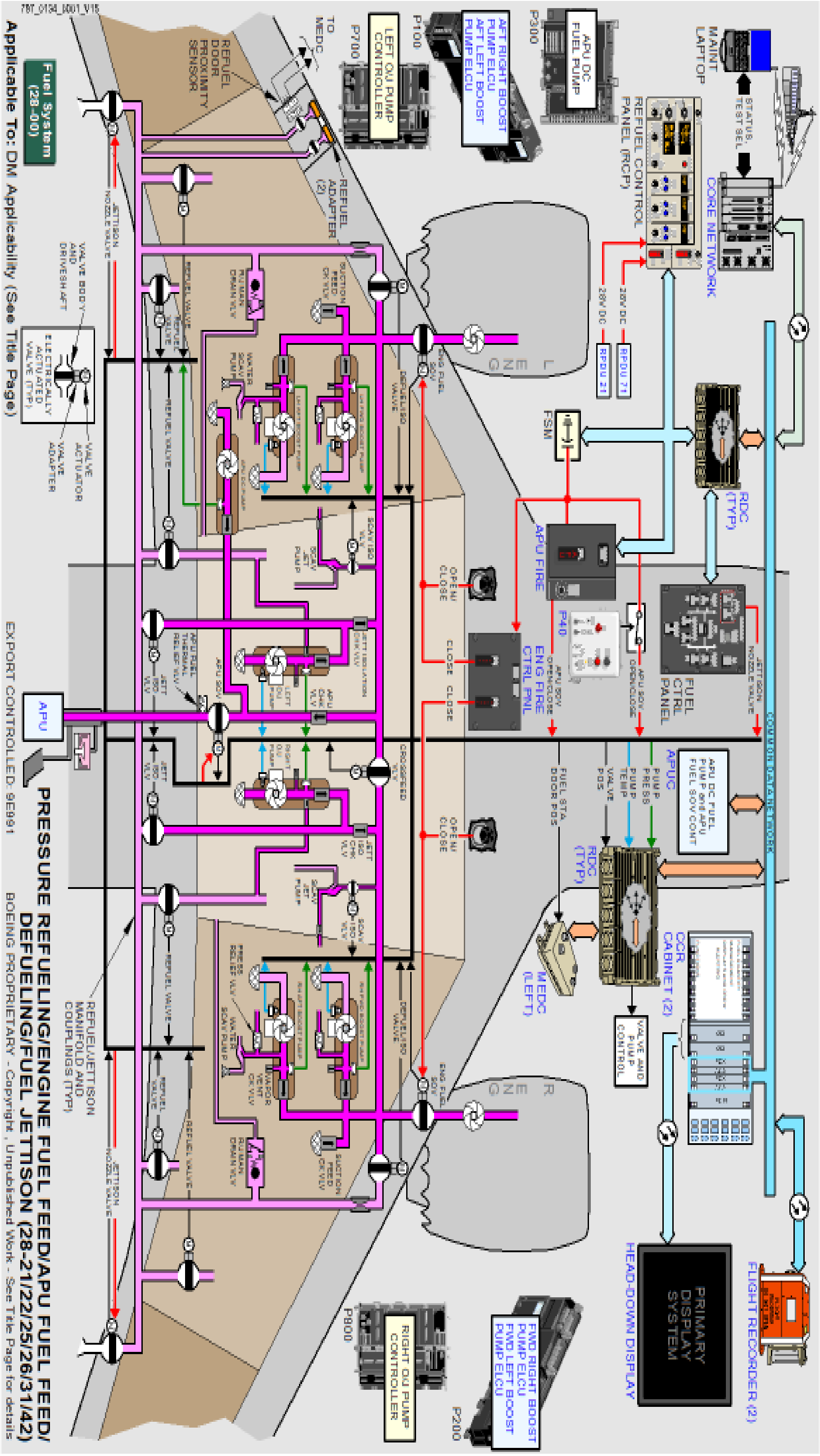


Figure 8 - B787-9 aircraft fuel system schematic

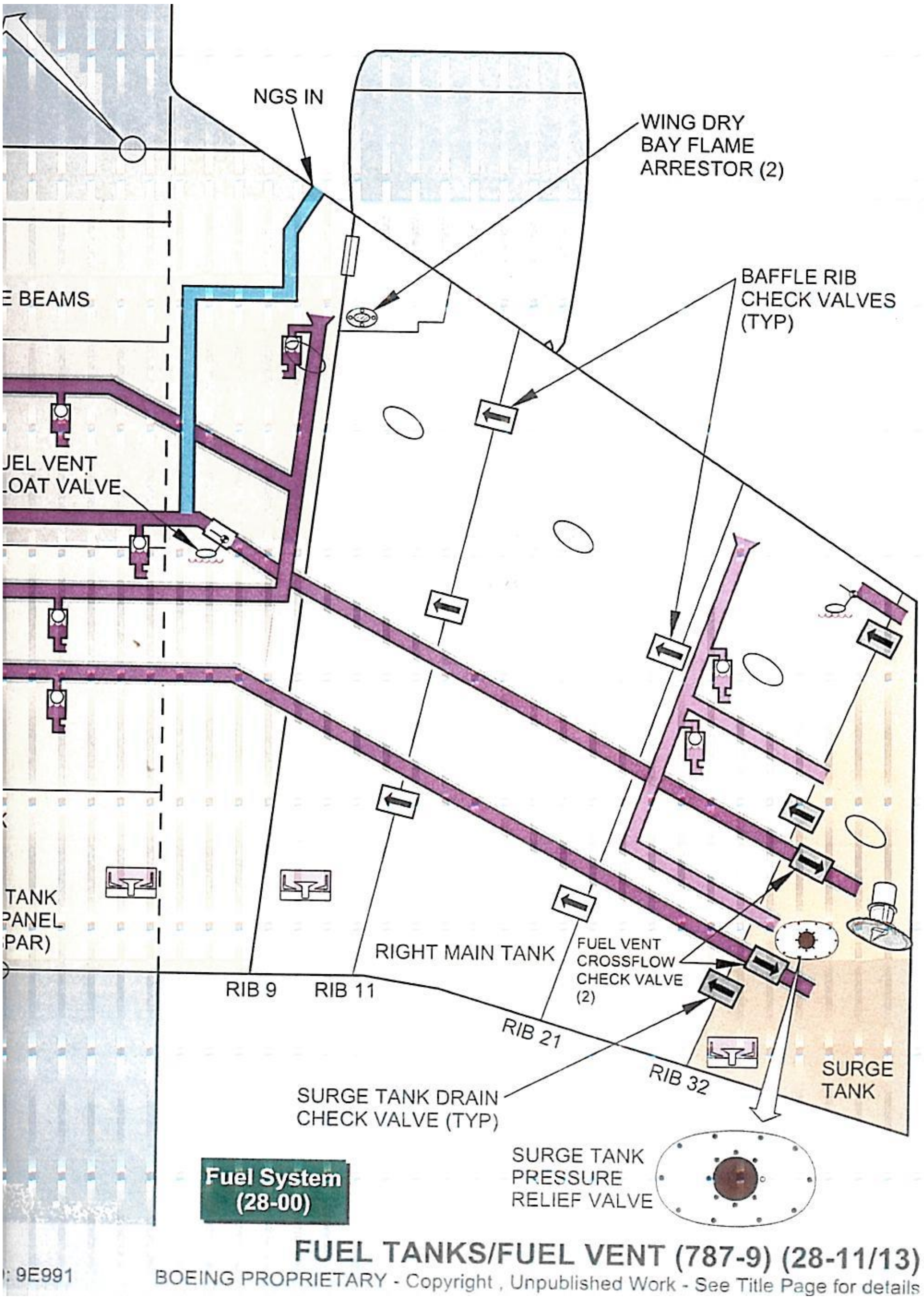


**Figure 9 - B787-9 aircraft fuel system vent and drain tubing schematic**

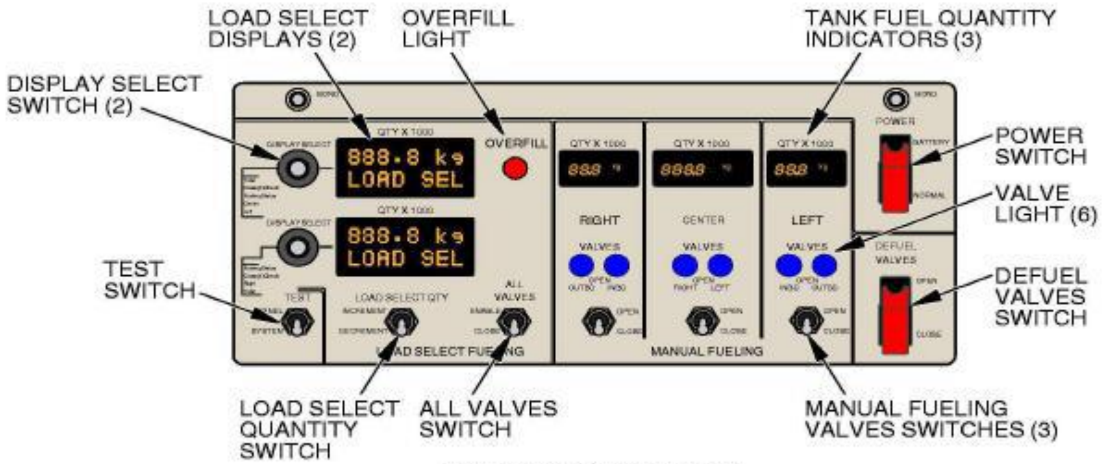


**Figure 10 - LH wing refueling panel (RCP)**

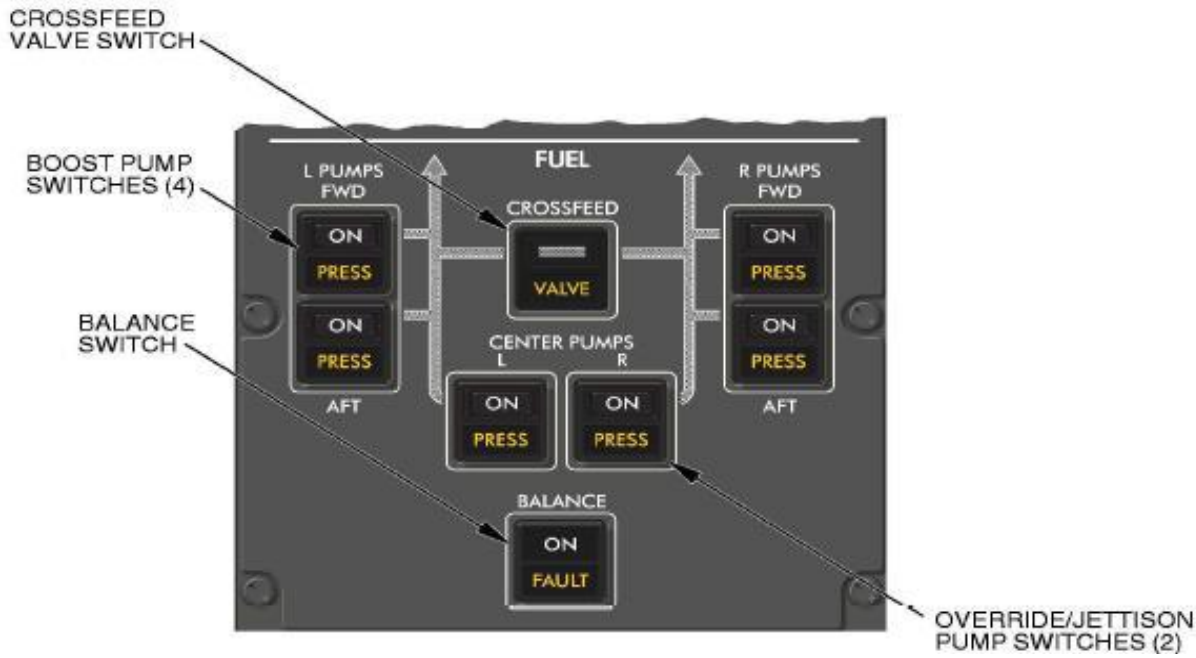


**Figure 11 - Fuel panel (P5)**

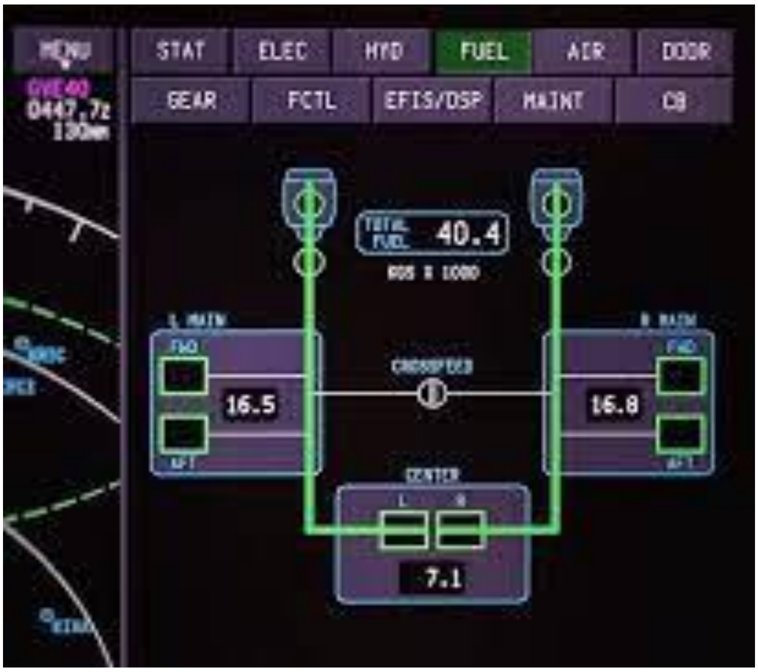


**Figure 12 - Fuel system SYNOPTIC display**

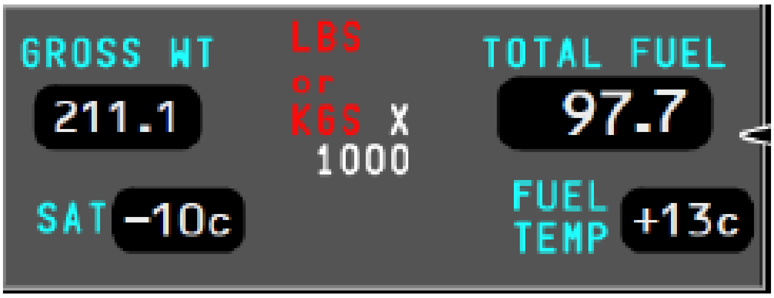


**Figure 13 - Fuel display, normal state**

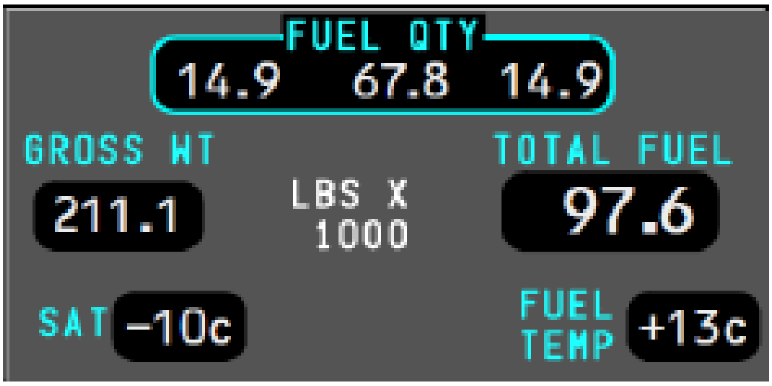


**Figure 14 - Expanded fuel display**

(Is displayed before start up and during malfunctions)

**Enables displaying fuel quantity in individual tanks**


**Figure 15 - Fuel display during fuel imbalance**

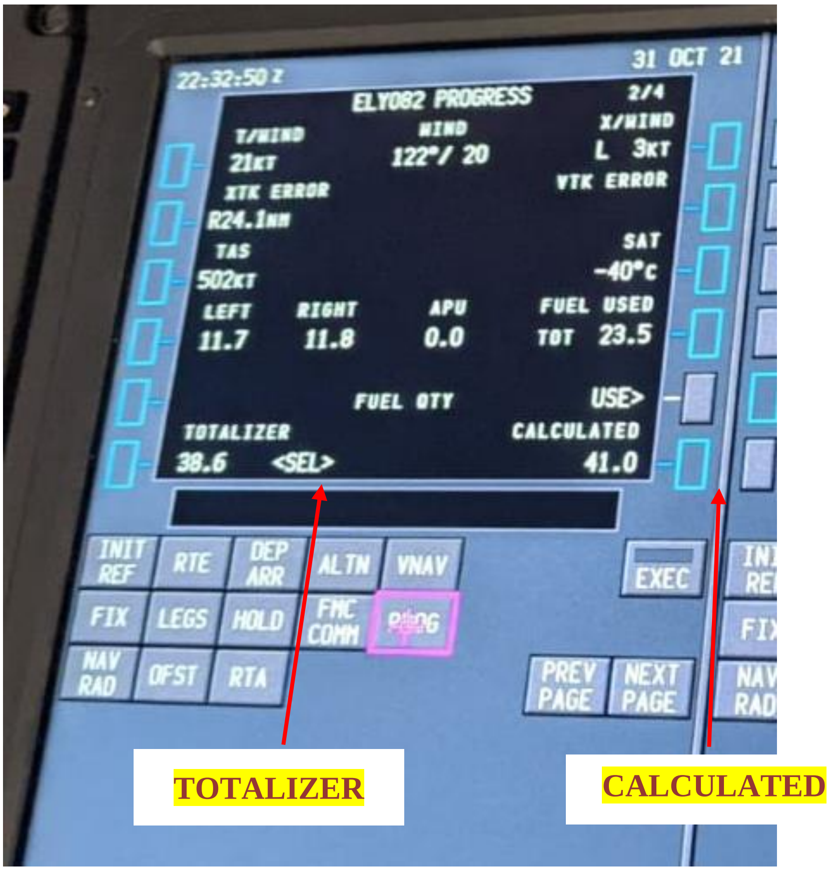


**Figure 16 - FMC Progress Page 2 image**

*Note: Fuel TOTALIZER and CALCULATED quantities are indicated*

The **Calculated** data are obtained using a computer that receives the fuel flow data from Fuel Flow transducers ahead of the engines, and performs a calculation of the fuel quantity in the aircraft after completion of engines startup, and a reduction at the amount of fuel consumed by the engines. The FMC calculates the expected fuel (according to the expected consumption), at forthcoming points up to flight destination.

The **Totalizer** data are obtained from calculation of fuel weight in the aircraft tanks (according to the volume) and is affected by a number of parameters such as: density, temperature and its location in the tanks, depending on varying flight conditions (Pitch angle).

A relatively large difference (of about 1,000 kg and more) can appear for short durations in varying flight phases (especially in the Climb and Descent phases).

A difference of about 100-200 kg is within the range of measurement errors and does not indicate a leak.

Leak detection that occurs ahead of the engine (before the measurement component) is possible by comparing the actual fuel quantity in the tanks (Totalizer) to the quantity planned in the Flight Plan.

The **FUEL DISAGREE** message alert depends on several parameters, and appears when there is a difference between the TOTALIZER and CALCULATED (these parameters are not listed in the FCOM publication).

In the subject event, the message came on upon a difference of approx. 2,400 kg between the TOTALIZER and CALCULATED.

**Fuel system mode of operation**

Boeing directs operation of 2 Override/Jettison pumps (when there is fuel in Center Tank), as well as 4 Main Tanks Boost pumps upon appearance of "Fuel in Center" message. Since the Override/Jettison pumps have higher flow and pressure, they will be supplying fuel to the engines. Only after substantial decrease of the fuel level in Center Tank (to approx. 2.1 tons) and "Fuel Low Center" message coming on, the pilot will shut them OFF and then the Main (wing) Tanks' Boost pumps will supply fuel to the engines from the Main Tanks.

In case of in-flight imbalance between L and R Main Tanks, which will cause "Fuel Imbalance" alert message to illuminate, the Balance switch on fuel panel P5 (see Figure 12) may be depressed. This will activate automatic fuel balancing and direct fuel transfer from the "heavy" wing to the "light" wing, until the Main Tanks fuel quantities will be balanced.

Notes: ***This action is possible only when the Center Tank Override/Jettison pumps are deactivated (OFF).***

*Fuel balancing can be performed on the ground, without starting the engines, by means of the Balance button.*

The fuel Jettison system is activated by the Jettison panel in P5. The system has first to be armed by depressing the ARM switch and then the landing weight can be entered by the Fuel to Remain selector (the default is entering the fuel quantity which corresponds to the max landing weight, which can be modified). Finally, the L and R Nozzle switches should be depressed for activation. Indication is provided in the SYNOPTIC page and the operation can be terminated at the desired/adequate fuel quantity.

### 1.18.11 Boeing recommendations for troubleshooting the discrepancy in the A/C:

- ☒ Check the fuel system for FOD.
- ☒ Check the manifold tubing for cracks, according to 787-FTD-28-180001.
- ☒ Refuel/Jettison and Fuel Feed Manifold Leak Test, per AMM DMC-B787-A-28-21-00-12A-364A-A.
- ☒ Engine Fuel Feed Manifold, Shutoff and Crossfeed Valve Leak Test, per AMM DMC-B787-A-28-22-21-01C-364A-A.

1.18.12 **Maintenance activities on the aircraft for troubleshooting the discrepancy (according to the maintenance manuals):**

- ☒ Visual inspection of the wings and engines, in order to detect indications of fuel leaks. Conducted by a company technician, while the aircraft was parked in Goa.
- ☒ External inspection of the surge tanks. No fuel traces or fuel odor were detected. Conducted by a company technician about 2 days after the landing at Goa.
- ☒ FIM were conducted due to the "Fuel Imbalance" and "Fuel Disagree" messages. No root cause detected. Conducted by a company technician, while the aircraft was parked in Goa.
- ☒ Engine runups were conducted for 2 hours, at various combinations of pumps' operation (Override/Jettison pumps, Boost pumps, Scavenge pumps) and engines feed, as well as several positions of the Crossfeed valve – no root cause detected. Conducted by a company technician, while the aircraft was parked in Goa.
- ☒ Two tubes, Manifold P/N 783Z2610-3/783Z2610-5 were removed from LH and RH wing main tanks and inspected for cracks in accordance with Boeing document 787-FTD-28-18001, which deals with developing of cracks in these tubes after 17,000 flight hours (cracks were found on 18 airplanes). These two tubes were replaced.

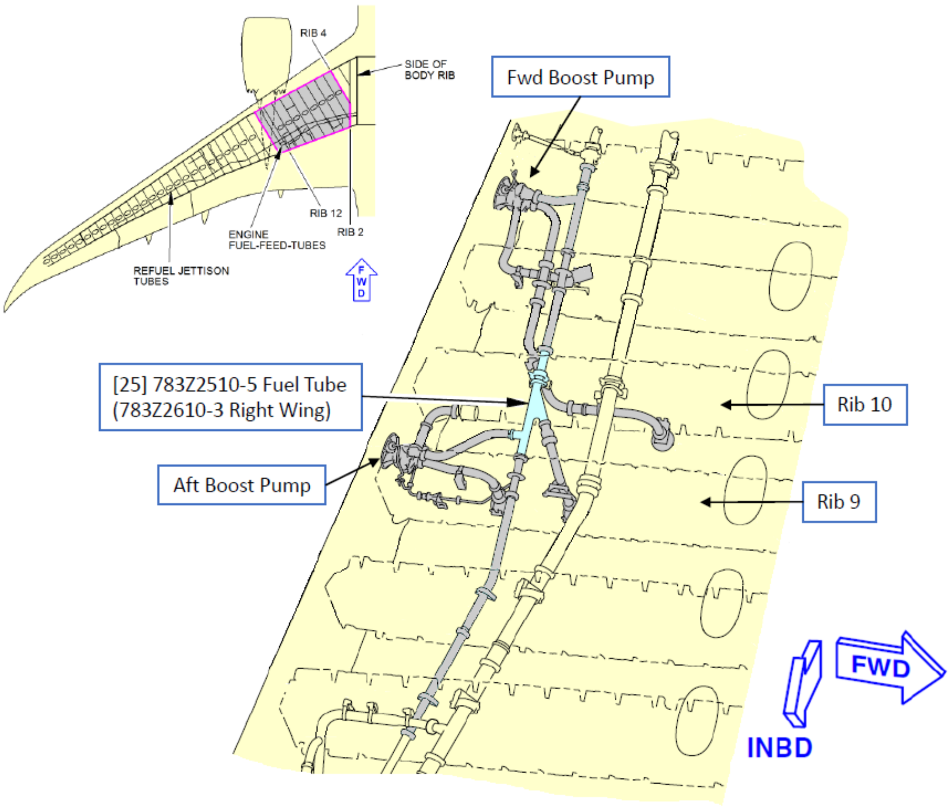


**Figure 17 - Location of suspected manifold tube**

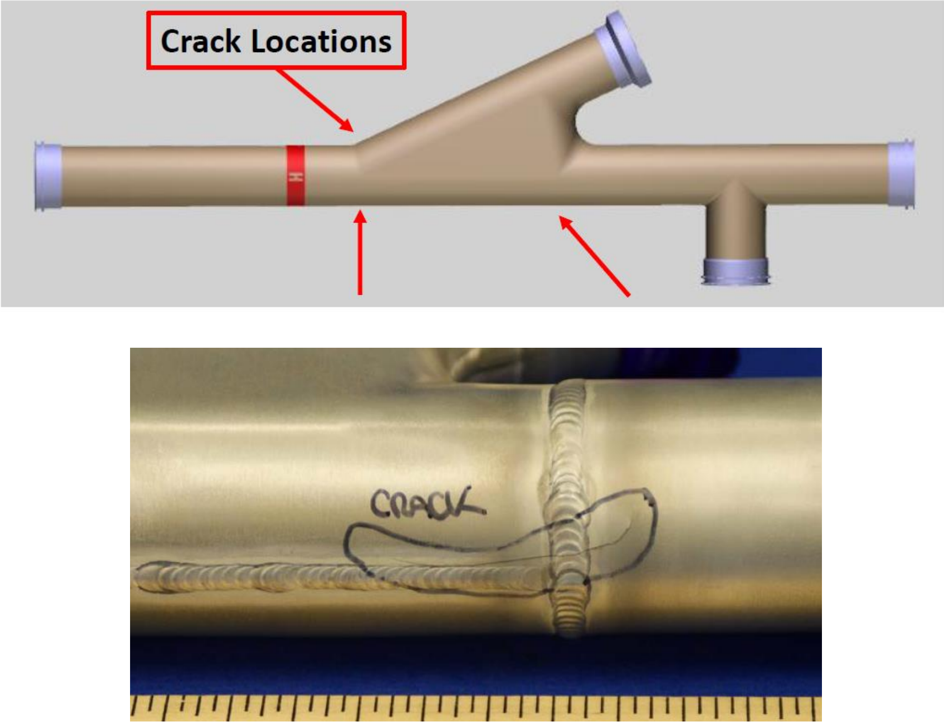


**Figure 18 - Location of cracks found in such tubes in the past**

- FOD inspections were conducted in the Main tanks, Center tank and valves and filters at the fuel tanks and engines – No findings.
- Fuel tanks and tubing were pressurized at 38 Psi for 10 minutes. No leak or pressure drop was detected.
- Check valves were inspected for functionality and found adequate.

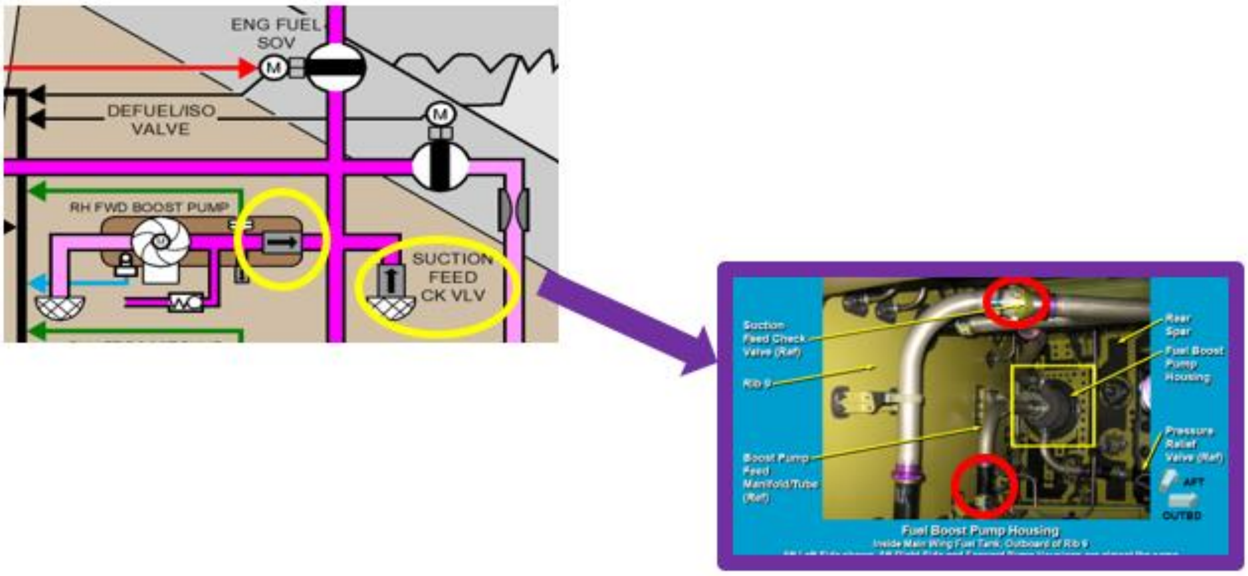


**Figure 19 - Check valves suspected as discrepant**

- ☒ Inspection for water in the fuel tanks was conducted – No findings.
- ☒ The investigation did not include inspection for contamination of the Bangkok airport refueling storage tank, nor of the fuel truck/pump which was used to refuel the aircraft.
- ☒ The aircraft was ferried from Goa to LLBG on November 10, 2021, (according to Boeing recommendation), with the Override/Jettison pumps in center tank OFF and the engines were fed by the wing boost pumps from the Main Fuel Tanks. Center tank fuel was transferred to the wing tanks by the scavenge pumps. The flight was accomplished with no abnormal events.
- ☒ A verification flight was conducted in Israel on November 15, 2021, under the same fuel and climb conditions as the event flight - No events and no special findings. Following this flight and at the operator's request, the Chief Investigator has released the aircraft from the investigation and CAAI approved its return to line operations. The aircraft has since conducted numerous flights, with no fuel system events or discrepancies.
- ☒ <u>Scenarios covered by the maintenance activities</u>:
  - o RDC data communication between the fuel system and other related aircraft systems was checked for functionality - No finding.
  - o Aircraft data was checked with Flight Data Recorder - No finding.
  - o All tests were performed for the [presence of external fuel leak - no findings.
  - o Pressure tests were performed on the fuel pipeline to detect a leak - no findings.
  - o Check valves (one-way) were tested - No finding.

    *<u>Note</u>: This is considered as the high probability scenario in the event flight.*
  - o The fuel tanks were physically accessed to inspect for a foreign object which might be clogging a fuel suction opening - No finding. **This is the highest probability scenario.**
  - o Engines fuel filter were replaced by new filters - No FOD found. *<u>Note</u>: This scenario most likely occurred on the flight of the event.*
  - o Lengthy engine run-ups were conducted trying to duplicate the flight malfunction phenomenon on the ground - No finding (both in Goa and in Tel Aviv).

### 1.18.13 Crew inflight actions regarding fuel

Following the refueling at Bangkok, the crew checked fuel data according to the procedures and signed the weight and balance form, which includes the fuel quantities in both wing tanks and in the Center Tank.

The crew noted that L and R Main Tanks fuel quantities were equal. Company procedures do not include a specific requirement for such a check.

The crew checked whether the refueled quantity satisfies the operational and regulatory requirements and stated that they found it adequate as follows:

- Weight added above the flight plan was 2.1 tons, fuel added by the crew was 1.5 tons, which was suffice for both the additional weight and for weather detours.

- According the operator's procedure, total added weight in excess of 3.6 tons requires issuing a new flight plan.

According to OM-A paragraph 8.1.9.1:

A new OFP shall be prepared in case any of the parameters below have changed:

- Change in TOW of more than: 777/787: +3,000 kg or -6,000 kg.

In order not to delay the departure, the crew set off with the original Flight Plan and according to the PIC's interview, he planned to receive an updated Flight Plan once in the air, in accordance with what is written in OM-A which allows it. The investigation team found no evidence for an updated Flight Plan.

Following the appearance of the "Fuel Imbalance" message, the crew executed the "Fuel Imbalance" checklist, as specified.

The crew tried to balance the fuel according to the checklist but did not succeed (because the center pumps were operating) and therefore returned the switches to their original positions (**in contradiction** to the Fuel Imbalance checklist).

About 15 minutes later, the crew executed a second attempt to balance the fuel per the checklist, in order to make sure there was no mistake in the first attempt and again, it did not succeed, so they returned the switches to the original positions.

The next fuel check was performed about 45 minutes after takeoff (according to Calculated data) and was found adequate.

A fuel check is typically conducted concurrently with recording it on the flight plan. For about 1:15 hours after the previous check (about 2:30 hours since takeoff) the flight plan has no record of fuel quantities. The crew said they made additional checks, which were not recorded.

In flight fuel monitoring by the crew was based **only** on Calculated fuel, until the "Fuel Disagree" alert message illuminated.

Following the "Fuel Disagree" message coming on (about 2.5 hours after takeoff), the crew performed the "Fuel Disagree" checklist, which has "led" them to perform the "Fuel Leak" checklist.

The crew performed the "Fuel Leak Checklist" and stated that they decided to shut down the LH engine according to the checklist.

The crew landed at Goa airport with no further unusual events.

## 1.19 Investigation methods

The investigation was conducted by a team of investigators from the Chief Investigator Office, and with the participation of an observer from El Al.

The investigation included:

- ✓ Interviewing the flight crew.
- ✓ Interviewing maintenance personnel who were on board.
- ✓ Interviewing pilots (currently active in El Al and former 787 pilots).
- ✓ Interviewing operations managers.
- ✓ Interviewing on-board technicians.
- ✓ Interviewing engineers.
- ✓ Interviewing the OCC chief air operations officer.
- ✓ Interviewing the MCC manager.
- ✓ Interviewing the manager of aircraft communications.
- ✓ Using manufacturers' data (Boeing, Eaton, Rolls Royce).
- ✓ Using technical data from the operator and the manufacturer.
- ✓ Review of the aircraft publications, with emphasis on the fuel system.
- ✓ Review of operation manuals, with emphasis on Non-normal operations.
- ✓ Training on the fuel system by a Boeing-qualified instructor.
- ✓ Examining the ECL of aircraft 4X-EDA, in comparison with the hard copy QRH.
- ✓ Analysis of data from FOQA, DFDR (EAFR) and FMF.
- ✓ Analyzing flight data.
- ✓ Involvement of and support by the NTSB.
- ✓ Obtaining answers from the aircraft manufacturer Boeing.
- ✓ Review of similar events worldwide.
- ✓ Review of studies from around the world, by way of troubleshooting.

## 2. Analysis

### 2.1 General

This investigation deals with **two aspects**:

- ✓ The technical aspect of the fuel leak – detecting its source and root cause.
- ✓ The operational aspect – the way the discrepancy was handled (identification, decision making, management throughout the flight).

<u>The technical aspect</u>

The aircraft had a discrepancy of **fuel migration** from the Center Tank to the RH wing tank (R Main), from there to the RH surge tank from which fuel spilled overboard via the RH vent scoop.

According to the manufacturer (Boeing), fuel migration from Center Tank to a wing tank can occur due to one of two reasons:

- ✓ A leak in the tubing from the Center Tank, which is routed inside the wing tank.
- ✓ FOD discrepancy, which causes a check valve inside the wing tank to remain partially open.

  *<u>Note</u>: Two such discrepancies have previously occurred on B787 aircraft.*

<u>The operational aspect</u>

A special emphasis was given to the discrepancy being **"unusual"**, and essentially it is only partly responded to by the checklist (see paragraph 2.3 for discussion of an **"unusual"** discrepancy).

The crew actions were examined relative to company procedures and Boeing's directives and recommendations, as well as among the crewmembers themselves.

The investigating team has focused on the flight crew actions while dealing with the malfunction, up to the stage of engine shut down.

### 2.2 Discrepancy description

A fuel leak (from a fuel tank and/or the engine) is mostly characterized by a decrease of the fuel quantity in the compatible wing or fuselage (center) tank and is manifested by a decrease in total fuel quantity by a higher rate than expected/normal.

When the leak occurs in one of the Main Tanks, its fuel quantity in that wing decreases faster and will usually be lower than on the other side's Main Tank. This phenomenon, along with fuel displays and dealing with leaks, are learned and exercised in various trainings, including at the simulator training.

The way for handling a discrepancy is "fixated" in the consciousness of pilots until it becomes "second nature".

In this event, the discrepancy was characterized by **fuel migration from the Center Tank to the R Main Tank** (RH wing). When the R Main Tank became full, the fuel migrated from R Main Tank to the **R Surge Tank** and when this tank was full, fuel began spilling overboard via the **R Vent Scoop** at the RH wingtip.

*Note: Analysis of DFDR data indicates that the leak rate was approximately 15 kg/minute.*

In **this "unusual" discrepancy**, the leak out of the aircraft was actually from the **R Surge Tank**, which spilled the excess fuel **from the wing with the higher fuel quantity**. The crew acted according to the "Fuel Imbalance" checklist, but their response to the discrepancy was not compatible with checklist, as follows:

- The "Fuel Imbalance" checklist includes a **specified list ("closed")** of indicators pointing to a suspected fuel leak.
  According to these indicators there was no suspected leak.
- According to the "Fuel Imbalance" checklist the crew should not be balancing fuel between the wing tanks when Center Tank O/J pumps are ON.
- The "Fuel Disagree" checklist refers/directs the crew to deal with the wing **"having the lower fuel quantity".**
- The fuel leak test per the "Fuel Leak" checklist was "interrupted", due to the activation of the LH Center Scavenge pump after about 20 minutes, which interfered with the process (see Figure 3).

Consequently, the crew elected to shut down the engine on the opposite side of the leak (the wrong side, as explained below).

### 2.3 Characteristics of "unusual discrepancy"

The vast majority of the discrepancies are trained, exercised and become familiar to the pilots, and the checklist response is professional and adequate. However, there may be **rare cases** where a discrepancy is not described in the publications and/or is not known to the manufacturer and/or is not resolved by the checklist and/or is neither studied nor exercised by the pilot (hereinafter "**unusual discrepancy**").
An "unusual discrepancy" can also be attributed to a "consequential" discrepancy, where the title in the checklist might be an outcome/symptom/secondary discrepancy of a primary malfunction.
Such rare cases should be detected by the flight crew through examination of the information, situation analysis and among other things, the crew should exercise judgement as best practice regarding the desired resolution, and in **highly unusual** cases they should even consider acting contrary to the checklist.
This approach is supported by the manufacturer's and operator's publications (as detailed in paragraph 1.18.2).
It should be emphasized that the above applies to an **extraordinary** discrepancy, not to a "**usual**" one which is known, trained and fully responded by the manuals and checklist (see explanation in paragraph 1.18.2).
An "unusual discrepancy" can also occur in the case of several discrepancies that appeared simultaneously, combined and/or not combined, and/or in the case of several systems that failed simultaneously, with or without a connection between them.

The discrepancy in this event belongs to the category of "**abnormal**" discrepancies which was not known, had no answer in the checklist (as mentioned above), and the crew was required to act in a way that they neither knew nor learned to deal with.

<u>*Notes*</u>:

- ✓ *The investigating team opines that every malfunction should be analyzed (whether it is "usual" or "unusual"), in order to enable identifying the "unusual" discrepancies (as written by the manufacturer and operator, see paragraphs 1.18.2-1.18.4).*
- ✓ *There are "**unusual discrepancies**" which are very difficult to detect in real time, especially when there is an apparently clear EICAS message. The crew did not have clear tools to actually analyze the discrepancy. Even approaching maintenance personnel would not necessarily have helped the crew, in view of the fact that they too were not familiar with such malfunction. In such cases, the primary insight of the crew can be that the checklist is not providing a response to an actual discrepancy.*
- ✓ ***Given the characteristics of the subject event's unusual discrepancy, it is not inevitable that other flight crews (of the company) would have acted in a similar manner to the subject crew**.*

## 2.4 The fuel system

The B787 fuel system is fairly complicated with limited details in the FCOM. Furthermore, the system schematic does not present all its components. The presented status for opening and closing valves are presented partially, so that some of them remain as "black holes" in the ability to understand the system operation and logic (see paragraph 1.18.10).

Thus, for example, in the manufacturer's publications there is no detail about the fuel system regarding the operation of the Surge Tanks, no possible malfunction is mentioned regarding fuel migration from Center Tank to Main Tank, then from Main Tank to Surge Tank and spillage overboard. Such fault was not known to the operator and to the pilots.

The fuel system "Non-Normal" checklist for this aircraft type is complex. It includes checks and conditions which could not always be understood (in real time), relative to the events on the subject aircraft (as detailed below).

The B787 fuel system includes features which have affected the event:

- The system has a **Balance** switch, which enables fuel balancing between the Main Tanks, by means of **direct fuel transfer from one Main Tank to the other.**

  On most aircraft types, balancing is conducted by cross-feeding, so that the "heavy" wing feeds both engines until its fuel level decreases and equals the "light" wing quantity.

  Fuel balancing on the B787 can **also** be implemented by cross-feeding, as described above.

Balancing of fuel in either of the two above methods, requires that **both Center Tank O/J pumps should be turned OFF.**

<u>Note</u>: *Turning OFF a Center O/J pump (only) on the "heavy" wing side will also balance the fuel between the* Main Tanks. *This is not written in the Checklist.*

- The B787 Fuel system includes a non-electrical **Scavenge pump**. Its features differ from other aircraft in two aspects: **flow rate** and **timing of activation**. The Scavenge pump transfers fuel from Center Tank to a Main Tank (left or right) when the Center pumps are not operating. The Scavenge pump comes on when the fuel in Center Tank is depleted, and the Center O/J pumps are stopped. This operation is performed by the pilot with the appearance of a message indicating low fuel quantity in the center tank, at about 2 tons remaining.
- Another mode of activation of the Scavenge pumps is when the fuel quantity in the Center Tank is high and the Center pumps are not operating. The Scavenge pump is automatically activated when fuel quantity in the Main Tank decreases below about 15,500 kg, and automatically stops when the fuel quantity in the Main Tank reaches about 16,700 Kg. The pilot has neither control of the Scavenge pump activation, nor does he get a message indicating that the pump has started or stopped. The only way for the pilot to see that the pump is operating is by examining the fuel system Synoptic display.

## 2.5 Inflight fuel migration

The aircraft was refueled in Bangkok with 64,700 kg, evenly distributed between the Main Tanks. Each Main Tank contained 16,400 kg and the Center Tank had 31,900 kg (per recorded data and refueling forms).

<u>Note</u>: *The crew reported that at the end of refueling fuel quantity in each wing tank was 16,300 kg.*

Since refueling up to start of taxi, the APU consumed about 200 kg (from left wing) and LH wing quantity decreased to 16,200 kg. RH wing quantity remained 16,400 kg. After engines' start, fuel began to migrate from Center Tank to R Main tank, due to the discrepancy. Taxiing was fairly short and the significant fuel status change was increase of R Main tank quantity to 16,600 kg, while LH Main Tank remained at 16,200 kg (see Table 1).

It should be emphasized that **after start up,** the pilots' displays **do not include fuel quantities in the wings.** Only total fuel quantity is displayed (see Figure 14).

After takeoff, fuel continued migrating from Center Tank to R Main Tank, due to the discrepancy (as described in paragraph 2.2). At that stage, the L Main Tank quantity remained constant (16,200 kg), while R Main Tank quantity was increasing. When R Main Tank quantity reached 16,700 kg, i.e., a difference of 500 kg, the "**Fuel Imbalance**" alert message illuminated. The message appeared while crossing 9,200 feet altitude, about 6 minutes after takeoff.

The crew commenced the "Fuel Imbalance" checklist, examined the checklist definitions of a fuel leak, noticed a difference of 100 kg between Totalizer and Calculated (a small, reasonable difference), noted a symmetric and correct engines' fuel consumption, observed no substantial difference between flight plan fuel quantity and the actual status, which led them to the conclusion **that there is no fuel leak.**

*Note 1: According to an analysis made by the investigating team, at that stage, there was still no fuel spillage from the wing overboard, but migration from Center Tank to R Main Tank which was not yet completely filled.*

*Note 2: The crew did not balance fuel by means of the Balance switch, because according to the "Fuel Imbalance" checklist, balancing cannot be executed while Center pumps are operating (see* Appendix *1).*

*The crew attempted* ***three times*** *to balance fuel in accordance with the "Fuel Imbalance" checklist, by opening the Crossfeed valve and turning off the L Aft Boost pump and L FWD Boost Pump. The quantity difference between the wings was not affected (fuel balancing was not accomplished). The checklist does not have a note indicating that fuel balancing by this method should not be conducted as long as the Center pumps are operating.*

The crew analyzed the reason for the inability to balance fuel and concluded that it was caused by the operation of the Center pumps, which along with having fuel in the Center Tank, is precluding Main Tanks fuel balancing.

The crew lack to detect an **unusual phenomenon**, where the fuel migrate to R Main Tank which **increased** the respective quantity from 16,300 to 16,700 kg.

Approximately 10 minutes after takeoff (following 4 minutes after "Fuel Imbalance" message coming on), R Main Tank quantity increased to 16,800 kg. Since that moment, fuel was migrating via the R Main Tank to the R Surge Tank, until it top filled and began spilling overboard. The aircraft began losing fuel from this point onward, as explained in paragraph 2.2.

1.5 hour after takeoff, when the fuel temp has cooled down (due to the surrounding ambient temp) while climbing, and its specific weight has changed, R Main Tank quantity increased to 16,900 kg and remained at that value for another hour (until the "Fuel Disagree" message illuminated).

During a timeframe of about 2 hours and 20 minutes, the difference of about 2,400 kg between the Totalizer and the Calculated quantities has been accumulated, while the crew was not aware of it, because this information is not displayed to the crew on the flight instruments. This difference can only be tracked and viewed in the "FMC Progress 2 page" (Figure 17). The crew did not re-examine the difference between the Totalizer and the Calculated quantities since they finished dealing with the "Fuel Imbalance" checklist, until the illumination of the "Fuel Disagree" message.

The crew performed fuel monitoring about 45 minutes after takeoff, using the Calculated parameter (which presented a "calculated", not "actual" fuel quantity).

The crew stated that they had to deviate from the planned route in order to detour clouds, and hence, could not examine the status using the Totalizer (which presents the actual fuel quantity in the tanks), because they had not overflown the flight plan's waypoints.

*Note 1: For a possible way to perform a fuel consumption test according to the TOTALIZER, see paragraph 2.7.*

About 2.5 hours after takeoff, when the "Fuel Disagree" alert message illuminated, the crew performed "Fuel Disagree" checklist, which led to conducting "Fuel Leak" checklist.

*Note 2: The "Fuel Disagree" checklist directs the crew's attention to the wing with the lower amount of fuel (the left wing), thus contributing to misleading the crew.*

In the course of conducting "Fuel Leak" checklist and trying to detect the leak, the crew turned OFF the Center pumps. This has created a situation in which each engine was fed by its own side Main Tank, using the Boost pumps.

When the Center O/J pumps were turned OFF, Main Tanks fuel quantities were LH 16,100 kg and RH 16,900 kg. The crew lack to notice that R Main Tank **quantity had not been decreasing for 11 minutes**, because its tank was being replenished by the R Surge Tank, by approx. 400 kg, while on the left side the fuel quantity decreased according to the LH engine fuel consumption.

The crew did notice the difference of about 400 kg between the wing tanks (see Table 1) during the timing period taken of 20 minutes (out of 30 min as directed by the procedure). Once the R Surge Tank got empty, fuel began being consumed symmetrically and fuel quantities decreased symmetrically, i.e., the 400 kg difference remained steady for about 10 minutes (see figure 6).

When L Main tank decreased to approximately 15,200 kg (see explanation in paragraph 1.6.9), the L Scavenge pump of the Center Tank began operating and started filling the L Main Tank with fuel from the Center tank (see Figure 3). At this stage, R Main Tank fuel quantity was above 16,600 kg and therefore R Scavenge pump was not operating (yet).

About 20 minutes after the fuel leak check has begun, the trend has reversed and the gap began to narrow down.

This coincidence surprised the crew, as they could not figure out the increase and decrease of the difference between the main tanks fuel quantities of (wing tanks).

The crew checked the fuel system Synoptic and saw that the LH Scavenge pump was operating. They analyzed it and concluded by extrapolation, that if the pump would not have been operating, the difference between the main tanks would have been growing and would be compatible with the checklist definition of a "fuel leak", hence - a difference of 500 kg or more within 30 minutes. The crew determined that the activation of the Scavenge pump actually "disrupted" the fuel leak check leading them to their conclusion that there must be a leak on the LH side (L Main Tank or Engine).

According to their conclusion, the crew shut down the LH engine, in accordance with the "Fuel Leak" checklist.

## 2.6 Examining root cause

The investigating team examined the cause for the discrepancy of fuel migration from Center Tank to R Main Tank. Since the fuel tubes were inspected by the technicians after the event and no cracks and/or leaks were found, the number of possibilities left for the fault is highly probability rest upon - the failure of a check valve:

- Boost Pump Housing Check Valve (Figure 20).
- Suction Feed Check Valve (Figure 20).

The Center pumps pressure is significantly higher than that of the Boost pumps. Hence, in case of a failed Boost Pump Housing Check Valve, or of a Suction Feed Check Valve, it is possible for fuel to migrate from Center Tank to either Main Tank. It could not be determined with confidence which valve has failed, since after the refueling at Goa, the discrepancy did not reoccur. The investigating team analysis conducted jointly with NTSB, Boeing and El Al, indicates, at a high probability, that either the Boost Pump Housing Check Valve or the Suction Feed Check Valve of the R Main Tank has failed (see Figure 20).

Notes: *In the course of the investigation, Boeing has reported **18 cases** of fuel migration due to cracks in Main Tank Manifold tube – see document 787-FTD-28-18001 (see* Appendix *8), and another **7 cases** of fuel migration due to discrepant Boost Pump Housing Check Valve - see document 787-FTD-28-16004 (see* Appendix *9).*

*Additionally, the investigating team found 3 events of fuel leak due to fuel migration from Center Tank to Main Tank and a fuel spillage overboard was observed at the wingtip area (Vent Scoop) – see paragraph 1.16.*

*In 2 of the 3 above cases where fuel spillage was observed, its root cause **was not determined with certainty**, and Boeing has stated that it was **FOD** preventing proper operation of one of the valves.*

**In summary** – An "unusual" discrepancy of fuel migration from Center Tank to **R Main Tank** and hence to the R Surge Tank and outside the aircraft, which is not described in the manufacturer's publications and is not familiar to pilots, has been considered by the crew as **L Main Tank** or **LH Engine** leak and led to shutting down the LH engine.

Following the LH engine shutdown, the crew declared emergency (MAYDAY) and diverted to Goa for a single engine landing. Approach and landing were accomplished with no further special events.

## 2.7 The operational aspect

The operator's procedure for fuel checking in flight (see paragraph 1.18.6), does not specify the means or parameters for comparing aircraft fuel quantity and the OFP quantity status. Namely, whether the amount of fuel is to be checked according to the TOTALIZER or the CALCULATED data, whether according to their lowest, highest and/or average value, whether in the event of a fuel shortage it is advisable to check both parameters, **or any other definition**.

The crew performed the fuel consumption check in flight, comparing the calculated amount of fuel (CALCULATED, which as stated presented an incorrect amount of fuel), versus the amount of fuel that should be according to the Flight Plan. No fuel check was performed according to the TOTALIZER when a deviation from the flight path was conducted, due to clouds (for a long period of time, close to 2 hours). Such an examination could have been performed, since it does not depend on the geographical location. The Flight Plan lists the waypoints with their designations, the **time** they will be reached and the expected amount of fuel that should be at each point. The anticipated amount of fuel at the **time** that appears at a particular point, can be compared to the amount of fuel in the aircraft tanks (TOTALIZER) at the **same time** (regardless of the aircraft's location in space). This process is not defined in the operator's fuel consumption check procedure.

Following the "Fuel Disagree" message, which were illuminated due to the difference between the Totalizer and Calculated values, the PIC took command, returned to the captain's seat and began dealing with the discrepancy.

The crew first concluded that there was a suspicion of a fuel leak after the "Fuel Disagree" message came on.

According to the "Fuel Disagree" checklist, which is oriented towards a fuel leak from the Main Tank/Engine on the side where the amount of fuel in the tank is lower (see Appendix 2).

The "Fuel Disagree" checklist refers to the "Fuel Leak" checklist for examining the possibility of a fuel leak.

Per the "Fuel Leak" checklist, the captain in command directed a mechanic and first officer to **visually** inspect for a possible wing or engine leak. The visual inspection covered the LH wing, the wing with the lower fuel quantity.

Several passengers had to vacate their seats for the visual inspection in order to enable better visibility of the wing and engine area. The mechanic illuminated the wing and engine with a flashlight, while the first officer looked through an adjacent window (to avoid being dazzled by the flashlight). Both have reported that the wing was visible up to the engine, as well as the nacelle, but not beyond the engine. Under the prevailing illumination conditions, the wing outboard of the engine and obviously the wing tip (where the Vent Scoop is) were not visible to the checking crew.

*Note: Even if the RH wing would have been being visually inspected for a leak (and it did leak from its wingtip), it is highly probable that the leak would have not been detected under the prevailing lighting conditions.*

Concurrent with not detecting an actual fuel leak from the wing (which is possible), the crew continued to search for **<u>the source of the leak per the "Fuel Leak" checklist</u>.**

The "Fuel Leak" checklist is attempting to detect a leak from 3 potential sources: Center Tank, Main Tank, or Engine.

**Finding the leak source per the checklist includes 4 stages:**

**<u>First stage</u>** - Checks whether the leak is from the Main Tank/Engine (left or right).

**<u>Second stage</u>** - If a Main Tank/Engine leak was not found, checks whether it is from the Center Tank.

**<u>Third stage</u>** - If the fuel leak is detected in the Main Tank **or** Engine, a process of shutting off the Engine and continuing to check whether the leak from Main Tank, if it was not in the Engine, should be performed.

**<u>Fourth stage</u>** - If a fuel leak was detected from the Main Tank (rather than the Engine), the Engine can be restarted. The complete process as defined in the "Fuel Leak" checklist (see Appendix 3):

The "Fuel Leak" checklist instructs to Turn the Center O/J pumps OFF, and check if a 500 Kg difference is created in 30 minutes, between the Main Tanks.

Within the initial 10 minutes, the change in fuel imbalance gradually increased to 400 kg (with a total difference of 1,300 kg between Main Tanks), and then stabilized for an additional 10 minutes, but then the trend has reversed and the imbalance decreased (L Main Tank fuel quantity began rising relative to the R Main Tank).

The crew was surprised by the trend reversal, checked the fuel display at the synoptic page and saw that the Center tank's L Scavenge pump commenced operating and began filling the L Main Tank (see Figure 3).

*<u>Note</u>: The checklist process does not mention the possibility of the Scavenge pumps activation and how to proceed in such scenario.*

Consequently, the crew decided that the 30 minutes check cannot be completed. They concluded that the difference would have reached 500 kg, had the Scavenge pump not commenced operation and that this is an indication of a left side fuel leak (L Main Tank or Engine).

*<u>Note 1</u>: The crew acted in this case contrary to the checklist, and subsequently received the company's backup.*

*<u>Note</u>: The crew has acted in the framework of considerations and decision making as detailed in paragraph 2.3.*

The crew proceeded to the fuel check 3rd stage, namely to check whether it is an Engine or Main Tank leak, and decided to shut down the LH engine as per the checklist.

In the descent, subsequent to the engine shut down, the wing fuel imbalance reached 500 kg and "Fuel Imbalance" alert message came on again, due to the engine shut down. This time the imbalance reflected a "light" RH wing and "heavy" LH wing. The imbalance and the respective EICAS message were triggered because the Center pump on the "live" engine side was deactivated, **in contraction to the instructions of the Fuel Leak checklist, paragraph 28**, which the crew has not accomplished.

Analyzing the DFDR data and previous sections in this safety report, revealed that the crew did not perform all the "Fuel Leak" checklist sections of the 3rd stage in the process, as explained above.

The captain in command decided to skip the 4th stage phase in the "Fuel Leak" checklist (as explained above), i.e., in order to refrain from additional 30 minutes leak check, as stated, which would determine whether the leak is from the engine or from the wing tank, thus giving up the option to restart the engine (if the leak is from the wing) and land with both engines operating. Instead, he decided to execute an immediate (single engine) landing. The reason being, that according to the NNC, OM-A and FCTM, in a situation of flight on one engine, the aircraft should be landed at the nearest airport.

*Note 1: With the subject discrepancy and under the actual conditions, where fuel migrated from Center Tank to the Main Tank and subsequently spilled out of the aircraft,* ***it was difficult*** *to detect the leak source according to the checklist, which was not fully compatible with the discrepancy at hand.*

*Note 2: In the investigating team's opinion, had the 4th fuel check stage been actually performed, the Center RH pump would have been activated as specified. This pump feeds the live engine. With a R Main tank filling rate of about 15 kg/min (due to the discrepancy) and R Main Tank fuel quantity of about 15,700 kg, the wing would not have been filled within 30 minutes. Therefore, the comparison of 500 kg in 30 minutes between the Totalizer and Calculated would not be different and the flight crew would have reached again the conclusion that* ***there is no leak*** *(see* Appendix *3),* ***apparently*** *the leak would be deemed stemming from the shutdown engine and the crew was not going to restart it.*

The crew considered whether to perform a quick fuel dump (jettison) before landing, because the aircraft weight on landing was higher than the maximum landing weight by about 10 tons. Nevertheless, the crew decided not to dump fuel, in light of the fact that the nature of the fuel malfunction was not clear to them. On the other hand, at the time of the event, the flight crew most likely realized that it had located the leak, even shut down the engine, and being near the selected landing field (Goa), dumping fuel would have allowed for landing within the limits of maximum landing weight.

## 2.8 Crew qualification

The flight crew (2 captains and 2 first officers) were qualified to conduct the flight. The crew members were familiar with the aircraft, the procedures, the systems and how it should be flown as they were trained. This is a typical crew of the company, which acted as instructed and trained over the years.

## 2.9 The human factor

### 2.9.1 General

Analysis of "human factors" issues, must take into consideration the purpose of the safety investigation, which is to prevent future accident or serious incident of the same type.

The analysis should be aware of the fact that some factors can be considered insignificant individually, but their combination can create the event.

In a safety investigation, it is important to evaluate the human being, and the causal connection of his presence and involvement with the occurrence of a safety event. Traditionally, investigations were focusing on "Unsafe Acts" conducted by individuals, which eventually ended in a safety event. The common concept nowadays is that the individual **is not operating on his own**, but is rather **a part/"component" of a complex system.** Such complex system can be defined as: "**Organization** of people and machines, which are acting and are being maintained in order to perform tasks which will meet the system's requirements".

Human factor investigation involves terms of probability and feasibility. Inductive circumstantial conclusions (**Inductive reasoning**), projecting from a singular case to a generalization are naturally less "precise" than deductive causal conclusions (**Deductive reasoning**).

The probability in such a context is not a product of "Mathematical accuracy", but rather the realization that projection from a singular case to a general case, **although did not happen in this case, it could have happened in it,** according to research based on similar cases in the past, which have been accepted by the "human factors" research community, as well as on supporting facts.

An inductive causal conclusion meets 3 criteria:

- ✓ Existence - The known facts and examination of human factors which affected the event.
- ✓ Influence - Establishing the probability that a human factor affected the event.
- ✓ Validity - The conclusions (under a certain probability) are based on undisputable facts.

2.9.2 Human factors investigation methodology

The human factors investigation methodology in an accident is primarily directed towards identifying the Safety Significant Events (**SSE**) out of the overall chain of actions which eventually led to the event.

Significant actions should be identified and isolated out of all the actions, those that had one of them been eliminated, the event would probably not have happened.

4 human factors topics are examined in this framework:

- **Unsafe act** (or unsafe lack of acting).
- **Preliminary conditions** (which led to unsafe act).
- **Latent failures** (at the level of pilot, management, regulator).
- **Organizational effects** - Typically at the management and regulator level.

Each of the above 4 topics is divided into sub-topics.

2.9.3 Insights into the human factor in a safety event

- ✓ An event is not an outcome of a single action by a single person.
- ✓ The potential for an event is created when human actions and **latent failures exist in the organization.**
- ✓ The objective of the "human factor" investigation is to detect the acts which led to "breaking through the defenses" and to the event happening.
- ✓ This detection dictates a decision to deal with the relevant latent failures - At all levels of management and regulator.
- ✓ It is important to understand and determine how unsafe acts can be prevented.
- ✓ Humans' errors are inevitable, but the frequency of their occurrence can be reduced and the severity of the results can be limited.

2.9.4 History of discrepancy management

**Clarification: This section does not relate to the subject incident and flight crew, but rather describes the history of fault handling in general.**

An accident in 1935 involved one of Boeing B-17's early models. Investigation found that the gust lock was not removed. Consequently, pilots concluded that the airplanes were becoming too complex to remember the correct actions and their correct order, and the required tasks should be written systematically. Thus, the first printed checklist was developed.

The next stage required generating another tool to assist with troubleshooting. A methodology for systems' training, understanding and failures detection began being utilized.

For years, Troubleshooting was the air crew person's main tool.

Troubleshooting in this context is:

"A logical, systematic search for the source of a mechanical problem in order to solve it".

In the course of training, the pilot studied the language of indicators and annunciator lights and burdened his memory with endless parameters and limitations. Based on this knowledge and on his flying experience, the pilot executed an orderly process for troubleshooting his aircraft's malfunctions and decided whether to perform a particular checklist or deal with the discrepancy differently.

The pilot's "success" or "failure" was mostly depending on the end result of the event and to a lesser extent on the way of action.

The aircraft manufacturers, regulators and operators were always concerned with the "liberty" taken by pilots upon a crisis and discrepancy, but had to accept such behavior pattern, due to lack of an alternative to Troubleshooting.

The world of aviation has moved from traditional knowledge-based learning products to learning in which the learner is able to assess situations and respond accordingly, recognizing that knowledge per se cannot be internalized and fully understood when detached from a realistic context.

Studies on the subject have shown that the effectiveness of the learning is increased, when the training is realistic (similar to the reality that the pilot will encounter in his aviation life), what is known as **Line Oriented Flight**

**Training (LOFT)**.

Training according to a scenario leads the learning through a situation or state and is based on the idea of “Situational Awareness”. Underlying this training method is the issue of decision making:

**ADM - Aeronautical Decision Making.**

ADM is a systematic approach to the mental process used by pilots to consistently determine the best course of action in response to a given set of circumstances

Technology improvements and the **"appearance" of the EICAS brought a revolution.**

EICAS message is being used both for determining the nature of the discrepancy and as a header for the applicable checklist.

Advanced aircraft have an electronic checklist (**ECL**), which displays the required NNC to the pilot and voids the need to open up the printed QRH.

The term "Troubleshooting" has now received a new meaning: Performing actions beyond the NNC's guidance, namely:

"**Troubleshooting** should only be considered when completion of the published non-normal checklist results in an unacceptable situation".

It is no more an integral part of analyzing and understanding the discrepancy prior to execution of the checklist.

The drastic reduction in the scope of material delivered to the pilot and the meagre information found in aircraft publications nowadays, further reduce the pilot's ability to perform troubleshooting, if and when required.

The Synoptic displays seem to be specifically intended to support troubleshooting. However, Boeing is stating that the crew actions should be according to the checklist, which is sufficient for managing and resolving a discrepancy and may be supported by graphic displays (see Appendix 7).

It is of importance to note that no NNC is requesting the pilot to make use of any synoptic display and no such graphic presentation is required for dispatching a flight (including fuel display).

The following B787 NNC quotations are worded identically to the NNC of most Boeing models:

The manufacturer, Boeing, expects that the capabilities of:

**"Good judgement"** and **"Captain's discretion"** available to anyone who was qualified as a captain, require refreshing and are always available, will support the pilot in situations where a discrepancy does not have a response in the checklist. But the pilot's superficial familiarity with the aircraft systems and his limited competence in analyzing, are casting doubt on his ability to meet such expectation and on his capability to deviate from the checklist.

The EICAS revolution and the adherence to the written word have caused pilots to impose upon themselves unwritten restrictions, which were not intended to by anyone. For instance, what is not specifically permitted in writing, is considering by many as forbidden, and an action which is not specifically directed - is being interpreted as prohibited. The pilots have embedded the policies of the regulators and operators and imposed upon themselves a highly restraining regime.

The requirements from a pilot are clear and precise, while permissions to deviate are specified in a manner which hardly allows to actually execute them.

Consequently, pilots typically operate by the checklist and do not deviate even when it is possible that the process is faulted.

A concept has crystalized that a pilot acting per the checklist "will not be criticized", while deviating from written procedures might be disputed (by colleagues/managers/regulators), with a low probability for a decision in the pilot's favor.

The FRM and FIM have affected maintenance personnel the same way that the EICAS has affected pilots. From being troubleshooters, they have become performers of procedures and tasks by the book. Their job did not become easier or less professional, but their understanding of the aircraft systems beyond dictated procedures has become meagre. Under these conditions, they have low capability to assist a pilot with resolving inflight problems, when such are not detailed and specified in the checklist/manual.

On the other hand, the manufacturer's introduction to the NNC is detailing many paragraphs, which **apparently** enable the pilot to analyze and comprehend the situation (see paragraph 1.18.2), but as mentioned above it is **neither trained** nor **implemented (nor in the simulator)**, and therefore the probability to implement it in flight, in real time is low (as will be detailed below).

In addition, the simulator training is "limited in time" compared to flights on the line, so the stage of locating, identifying, analyzing and examining the fault is greatly shortened in simulator training, and often is not performed at all, until it becomes a habit that may repeat itself on line flight, where generally there is time for identification, analysis and understanding of a malfunction.

2.9.5 Fault identification and analysis (general)

Fault identification and analysis is based by two terms: **Analyzing** and **Positive Identification**. These concepts are essential, but they are not clear enough, so Boeing the manufacturer refers (for clarification) to two FAA documents (see paragraph 1.18.7)

According to these FAA documents, fault analysis and handling include **four stages,** at the end of which the operation is evaluated and characterized by "**DECIDE**", an acronym for the stages as detailed below:

- **Detect** (the Problem)

  Problem detection is the first step in the decision-making process. It begins with recognizing a change occurred….

  … **an objective analysis of all available information, are used to determine the nature and severity of the problem**. One critical error made during the decision-making process, is, incorrectly detecting the problem.

- **Choose** (a Course of Action)

  After the problem has been identified and its impact estimated, **the pilot must determine the desirable outcome and choose a course of action**.

- **Identify** (Solution)

  The pilot formulates a plan that will take him or her to the **objective**…, the pilot solves the problem by identifying one or more solutions that lead to a successful outcome**. It is important for the pilot not to become fixated on the process to the exclusion of making a decision.**

- **Do** (the Necessary Actions)

  Once pathways to resolution are identified, **the pilot selects the most suitable one for the situation**. …

- **Evaluate** (the Effect of the Action)

  **Finally, after implementing a solution, evaluate the decision to see if it was correct. If the action taken does not provide the desired results, the process may have to be repeated.**

That is, the analysis of a fault, which includes the steps and actions described above, is conducted even before performing the QRH operations, in order to verify that the handling is carried out for the fault itself and not for another fault/problem.

The manufacturer (Boeing) recently updated (March 2022) the Introduction to the NNC, and inserted a paragraph of Analyze the Situation (see Appendix 4).

*Note: The FORDEC process conducted by the operator at the post-QRH stage is also an analysis, **but of a different kind**. It is designed to "**manage the event**" where the pilot examines the findings, the possibilities available to him, the risk in each possibility, their implementation and an examination that the choice was correct, and is still valid (for example: To which alternate to divert).*

**In this safety report, the use of the term "Analyze" refers to the analysis of the fault in the stage before performing the QRH operations.**

2.9.6 "Fuel Imbalance" discrepancy identification and analysis

The discrepancy in the subject event was **"unusual"** in nature, as explained in paragraph 2.3. After the "Fuel Imbalance" message came on, the captain decided to commence dealing with it after crossing FL100 (up to this altitude the crew is only performing urgent tasks and is focusing on flying the airplane).

After crossing FL100, the crew checked the fuel quantities' difference between the Main tanks, realizing it exceeded 500 kg and therefore determined that there is a state of "fuel imbalance".

The crew promptly initiated the respective checklist, with the ECL open (automatically) and displayed on the EICAS (see ECL explanation in paragraph 2.13), according to the company standards and procedures. The crew did not primarily consider to **examine carefully** the information presented, i.e - **what is the exact fuel quantity in each Main Tank**, and is it reasonable (appropriate for the conditions).

The NNC Introduction states:

**"Usually, time is available to assess the situation before corrective action is started".**

In addition, the crew failed to interpreted **why the "Fuel Imbalance" was generated**, and under what reason/s may have caused it.

All this prior **to commencing execution** of the checklist.

According to the **FCTM**, paragraph 8.1:

**"Non-Normal Situation Guidelines**

**ANALYZE THE SITUATION**: NNCs should be accomplished **only after** the malfunctioning system has been **positively identified**."

Although the crew knew that at the end of refueling the fuel quantities in the Main Tanks were equal at 16,300 kg, upon appearance of the discrepancy, L Main Tank quantity showed 16,200 kg, while R Main tank quantity showed 16,700 kg. This information, had it been noticed and analyzed by the crew, could have led to the insight on the existence of **abnormal and unusual in the scenario**.

Namely, an **increase** of Main Tank fuel quantity is abnormal, unfamiliar and unexplained.

It should be emphasized that the crew is not expected to remember by heart the refueling quantity figures, but is expected to act based on accurate and documented data, which apparently, they could have obtained.

The NNC Introduction states:

"While every attempt is made to supply needed Non–normal checklists, **it is not possible to develop checklists for all conceivable situations".**

The above manufacturer's statement refers to a combination of several malfunctions and/or malfunctions in several systems, but is also probable that a single malfunction in one system will create a scenario **for which the checklist has no response**, and the manufacturer should also provide answers for such cases.

At the end of refueling Main Tanks quantities were equal. **After startup and takeoff, the engines are fed by the Center Tank pumps.** "Fuel Imbalance" message came on 6 minutes after takeoff. The above facts should have been analyzed by the crew prior to commencing execution of the checklist.

**In the publications,** the NNC Introduction states:

**"Usually, time is available to assess the situation <u>before</u> corrective action is started".**

That is, aperiodic, including this case, there is time to examine **"Is it possible that <u>there is no fuel leakage</u> when there is fuel in the Center Tank, (which feeds the engines), and at the same time a significant difference is created between the wing tanks?".**

The NNC Introduction states:

"The condition statement briefly describes the situation that caused the EICAS alert message. The condition statements help in **understanding the reason for the checklist".**

Answering this question could have led the crew to the insight that **maybe** it was **not** appropriate to balance fuel, since the prerequisite for fuel balancing is that the crew **<u>did not suspect</u>** there was a leak. As described above, a leak could already be suspected at this stage, as written right at the beginning of the "Fuel Imbalance" checklist - that its objective is to examine that "Fuel leak **is not suspected**".

The intent is that the "Fuel Imbalance" checklist should be read for understanding and checking, but at the same time there should be an **assessment** which considered all information, and the insight of a suspected leak.

Since there is a **suspicion of a fuel leak**, beyond the "closed" list written in the checklist, and in the captain's opinion the possibility of a fuel leak should be taken into consideration, therefore this is the safe action to take.

The FCTM paragraph 8.30 states:

"Some fuel-related checklists (for example, FUEL IMBALANCE) specify reasons that a fuel leak should be suspected. **This list is not exhaustive** and, in all cases the **flight crew should use their knowledge on the fuel system and current operating conditions to determine whether a fuel leak should be suspected**."

The policy in the NNC Introduction states:

"In all situations, the captain **assesses the situation** and uses **good judgment to determine the safest course of action".**

The investigating team thinks that the flight crew did not fully understand the cause of the "Fuel Imbalance" message coming on at that phase of the flight. A possible explanation (see paragraph 2.9.5**) is the troubleshooting method utilized at the operator.**

Additionally, since this type of discrepancy provides time for in-depth examination (as explained above), it was possible to wait for the cruise phase and continue checking if there is a suspected fuel leak, rather than ruling out any suspicion for a leak during the climb phase. The tanks fuel quantity comparison versus the flight plan could be exactly checked during the cruise phase and not rule out the suspicion of fuel leakage at an early stage.

The Totalizer fuel quantity display in climb could be in error, due to the nose high attitude (relative to cruise). The difference between actual quantity and indicated quantity in climb **might reach several tons**. Therefore, when there is no time pressure, it is desirable to examine a suspected leak in level attitude (at cruise phase). See following explanation in the company's publication (FCTM).

The **FCTM** paragraph 8.30 states:

"Fuel sloshing (such as from high angles of pitch). Sloshing fuel would be a temporary effect".

Further, the reason for fuel balancing **is not controllability**, but rather airframe and landing gear structural life, and hence there is no need to hurry.

The **FCTM** paragraph 8.28 states:

"The primary purpose of fuel balance limitations on Boeing airplanes is for the **structural life** of the airframe and **landing gear** and **not for controllability".**

Therefore, **there is no need to expedite and conclude** that there is **no suspicion of fuel leakage**, in order to perform "Fuel balance".

As mentioned, the crew did not examine thoroughly the fuel data (other than reading that there is a difference of 500 kg between the Main Tanks), did not attempt to **analyze** the situation (as explained above) before initiating the checklist actions. **Apparently**, L Main tank is losing fuel while R Main Tank is "collecting" fuel.

The **FCTM** paragraph 8.1 states:
**"Non-Normal Situation Guidelines**
**ANALYZE THE SITUATION**: NNCs should be accomplished **only after** the malfunctioning system has been **positively identified**. Review all EICAS messages to **positively identify the malfunction system**(s)".

The investigating team thinks that the flight crew did not conduct an **analysis** of the situation, nor an accurate and complete **identification** of the discrepancy (before beginning to deal with it), thus acting in conflict with the company's written manuals.
It is highly probable that such action is an outcome of the **company's teaching, instruction and training methods, where the policy is to adhere to the checklist items.**
While conducting the "Fuel Imbalance" checklist, the crew found a 100 kg difference between the Totalizer and the Calculated data (a negligible difference at this flight phase), However, there is the 500 kg difference between the Main Tanks quantities, which is not reasonable at this stage, where all engines fuel is consumed from the Center tank (only). The reasons for the fuel imbalance at this stage of the flight **should have been discussed and examined by the crew**.
The publications state (as mentioned above):
**ANALYZE THE SITUATION** … **positively identify the malfunction system**(s)".

In this case, the imbalance was just the symptom for the discrepancy, not the discrepancy itself, which was the fuel leak.

Additionally, FCTM paragraph 8.2 states:
A supporting troubleshooting tool for the pilot under "unusual" situations:

- **Taking steps beyond a published NNC** in an effort to improve or correct a non-normal condition."
- "**Initiating an annunciated checklist without an EICAS alert** message to improve or correct a perceived non-normal condition".

The inability to accomplish fuel balancing per the checklist (after the illumination of "Fuel Imbalance" message), should have led the crew to examine why it happened and whether there is an additional/different problem which prevents the balancing.
Additionally, to conduct frequent in-flight fuel consumption checks with all available means, **in order to confirm that there is no suspected fuel leak**.

The investigation team examined the operator's training methods, the practicing methods in the simulator, and the operator's organizational culture and its compatibility with its official publications, as a standard course of action, and to analyze the situation, both in cases where the checklist is appropriate and in cases where the checklist is not appropriate.

The NNC Introduction states:

- "In all situations, the captain **assesses the situation** and uses **good judgment to determine the safest course of action".**

As an example, although the crew realized that the Center pumps must be turned OFF for Main Tanks fuel balancing, they did not do it.

Meaning, on the one hand the crew realized that it was not possible to balance fuel between the Main Tanks without turning OFF the Center pumps, and on the other hand, according to the recorded data the crew turned OFF the Center pump operation for a short time (about a minute), one pump at a time, which precluded accomplishing of the fuel balancing. According to the captain in command, they returned the pumps to operation immediately after stopping them, **contrary to the checklist**. The manufacturer referred to the action and stated that Center pumps may be stopped in order to activate the Balance switch, if the crew considers it the appropriate course of action, even though it is not spelled out in the checklist.

The NNC Introduction, states:

- "The flight crew must be aware that checklists cannot be created for all conceivable situations and **are not intended to replace good judgment**. In some situations, **at the captain's discretion**, **deviation from a checklist may be needed".**

On the other hand, the crew that failed to balance fuel (using the **Crossfeed** method), returned the switches to their previous (normal) positions, **in contrast to** the checklist.
*Note: This action **is contrary** to the checklist and was retroactively backed by the operator.*

The investigating team believes that according to the data and the flight conditions (immediately after takeoff), with Center Tank feeding the engines, it is compatible with the definition of FCTM paragraph 8.30, where the crew should conduct an analysis to examine a suspicion for a fuel leak:
"Some fuel-related checklists (for example, FUEL IMBALANCE) list reasons that a fuel leak should be suspected. **This list is not exhaustive** by nature, and, in all cases, the **flight crew should use their knowledge on the fuel system while using best judgement and current operating conditions to determine whether a fuel leak should be suspected**."

As mentioned, the crew should use its knowhow of the fuel system when going to analyze and determine whether there is a suspicion for a fuel leak (**even though the checklist definition of a leak is not completely met**). For example, has fuel transferred from one tank to the other not as expected?
All the above is compatible with the manufacturer's and operator's publications, which **grants the captain the authority to do so**.
**He should have evaluated the circumstances and conditions in depth, before deciding** to open **the Crossfeed valve** to conduct fuel balancing.

The investigating team emphasizes that since this was an **"unusual"** discrepancy, non-standard, with parameters which were not compatible with the checklist, it would have been appropriate to examine the suspicion for a leak during a longer time frame and not rule out a leak at an early stage.
Further, it is the investigating team's assessment that **it is probable that other crews of the company would have acted in a similar manner, in view of the fact that this is how they were taught, instructed and practiced.**

*Note 1: Notwithstanding the above, the investigating team has found that "Fuel Imbalance" checklist is incomplete and is not worded optimally, riflacted for example in: **on one hand Crossfeed** fuel balancing cannot be performed while Center pumps are operating and there is no directive to turn them OFF, while **on the other hand** the checklist contains no manufacturer's note stating that balancing cannot be accomplished as long as the Center pumps are operating.*

*Note 2: In March 2022, **while the investigation was still in process, the manufacturer has published a revision to the "Fuel Imbalance" checklist.***

### 2.9.7 Suspected fuel leak

The crew checked the fuel consumption according to company procedures (Actual fuel vs. Flight Plan). Company procedures do not define the checking method, whether to use as basis the **Totalizer** or the **Calculated** fuel (see paragraph 1.18.6).

Since it was done on basis of **Calculated** fuel, an abnormal fuel loss (leak) could not be detected, because this parameter is based on the fuel quantity consumed by the engines, which was not compatible with the actual quantity in the tanks due to leak in the main fuel tanks. In this event, had the fuel check been using the Totalizer, it is highly probable that the leak would have been time wised detected at an earlier flight stage.

Since the crew did not suspect a fuel leak, they did not check the FMC "Progress page 2" (see Figure 16) for about 2 hours (since their previous fuel check), until the "Fuel Disagree" message illuminated.

The investigating team assumes that the reason for the above resulted from the **lack of carrying out a full analysis** of the "Fuel Imbalance" message, as explained previously.

Following the appearance of a "Fuel Disagree" message, the checklist guides the crew towards the Main Tank with the lower fuel quantity, see checklist paragraph 2 in Appendix 2:

*"One main tank is **abnormally low** compared to the other tank, and to the expected fuel remaining in the tank"* (**bold** fonts are not in the original wording).

This might had contributed to the crew's misinterpretation.

*Note: The investigating team found that the above wording in the "Fuel Disagree" checklist is not compatible with the subject event's discrepancy **and might mislead pilots.***

### 2.9.8 Fuel leak checking

After the "Fuel Disagree" alert message illuminated, the crew followed the checklist, examined FMC Progress page 2 and found a difference in fuel quantity of approx. 2,400 kg. The crew also checked the **Totalizer versus the Flight Plan and found a difference** of about 2,900 kg.

The crew concluded that there is a leak and was referred to the "Fuel Leak" checklist. This process was conducted carefully, while thoroughly examining the information and the implications. Time interval from "Fuel Disagree" message coming on until turning OFF of the Center O/J pumps was about 25 minutes, **and indicates an attempt to fully comprehend the information.**

While performing the "Fuel Leak" checklist the crew was required to verify the leak source. They turned OFF the Center pumps according to the checklist and checked whether there was a 500 kg difference within 30 minutes. The checklist directs to record the data accurately and mark time by a stopwatch, which was done by the crew.

*Note: Subsequent to turning OFF both center pumps, each engine consumes fuel from the Main Tank Boost pumps on its side.*

Main Tanks quantity at the beginning of the test was 16,900 kg RH and 16,000 kg LH.

Although the crew has **written down this data,** they **did not notice** that for **about 11 minutes** the R Main Tank fuel quantity remained at 16,900 kg, while LH Main Tank quantity decreased by about 400 kg, compatible with the engine's consumption.

According to the checklist guidance, the crew concentrated on the difference between the Main Tanks and did not try to analyze what caused this difference, and how it was formed (since they did not notice that in the R Main Tank fuel quantity **did not decrease**, despite the RH engine consuming its fuel at that stage).

**According to FCTM** paragraph 8.1:

**Non-Normal Situation Guidelines**

"**ANALYZE THE SITUATION**: NNCs should be accomplished **only after** the malfunctioning system has been **positively identified".**

That is, according to the publications the data must be accurately analyzed and examined, and only then take the actions written in the checklist. Not recognizing such a significant figure while the data is being **recorded and examined**, prevented the crew from performing an intelligent analysis to understand the cause of the fuel difference created, or alternately, to come to the insight that there is something unexplained in the fuel system, and whether it is safe to continue the flight under these circumstances. **As stated above, this lack of recognition, with the contribution of the checklist not fully responding to the situation, has led the crew to the erroneous conclusion that there was a leak on the left side of the aircraft** (L Main Tank or Engine).

*<u>Note</u>: The investigating team thinks that the flight crew did not have the adequate tools for* ***analyzing and comprehending the fuel "behavior" in real time (nor would any other crew under similar circumstances),*** *but it was certainly anticipated that they should have noticed such an "abnormal" phenomenon (fuel quantity not decreasing in a wing feeding the engine), and in view of the situation (as well as the lack of a logical explanation for it), will elect to land at the nearest airport. I.e., a fuel leak on one hand and unexplained fuel "behavior" in the other hand.*

For another 10 minutes, the difference between the Main Tanks remained constant, and after 20 minutes from the leak test initiation, the fuel difference between the Main Tanks has begun decreasing and reversed its trend. The crew used the Synoptic, noticed that the Center L Scavenge pump has been activated, transferring fuel from Center Tank to L Main Tank and actually "spoiling" the test.

Consequently, the crew determined there is a leak from LH side.

The investigating team thinks that this flight crew's analysis, including the use of the Synoptic, was carried out **adequately** (per the manufacturer's manuals), in a situation where the checklist is not compatible with the information coming from the airplane.

The crew did not notice that the difference remained constant for 10 minutes, and they said that the difference increased until they have noticed the reversal of the trend after 20 minutes from the start of the test.

The NNC Introduction states:

"**In all situations**, the captain **assesses the situation** and uses **good judgment to determine the safest course of action.**

In some situations, **at the captain's discretion, deviation from a checklist may be needed".**

*<u>Note 1</u>: The investigating team thinks that the activation of the scavenge pump might be disruptive to the fuel leak check specified in the "Fuel Leak" checklist. It should be emphasized that the leak check's required duration is 30 minutes (see* Appendix *3), and in some situations,like this occurrence, it is* ***highly probable*** *that within such a time frame, at least one Scavenge pump will start operating.*

*<u>Note 2</u>: With a slow leak, up to 15 kg/minute, it is possible that a crew will not detect the leak* ***(per the checklist)*** *and a continuous leak might take place.*

*(15 kg/minute X 30 minutes = 450 kg, while the checklist defines a leak only when 500 kg are exceeded within 30 minutes).*

2.9.9 <u>The manufacturer Boeing</u>

The investigating team has determined regarding Boeing's publications (FCTM) about the use of the **Synoptic display**, that it is important to use the Synoptic as an integral part of gathering information, in particular when there are items whose operation **can only be retrieved by watching the Synoptic**, for instance: Activation of a Scavenge pump (see Appendix 7).

In addition, to clarify the term Analysis (see paragraph 1.18.8) the manufacturer refers to FAA document, stating:

"A problem is perceived first by the senses and then it is distinguished through insight and experience. These same abilities, as well as **an objective <u>analysis</u> of all available information, are used to determine the nature and severity of the problem"**.

2.9.10 <u>Summary of the "Human Factor"</u>

A safety investigation is trying to examine the process, actions and decisions made by the crew. It should not base its conclusions solely on the "end result criterion", since every mission combines man, machine, environment, management and organization - every component, as "marginal" as it may seem, might be the factor that drove the process or led to the event.

The systemic approach indicates that all components of a system have an active role in a safety event. Namely, even an event which apparently involves a single pilot, should be viewed as being a part of a broader system, to which it is related - directly and/or indirectly – and its role in the occurrence of the event should be examined.

Therefore, following a safety event, the safety investigation methodology guides the investigator, according to the safety concept, that the accident investigation "begins with the pilot" but typically does not end there.

As explained at the beginning of this chapter, per the methodology for investigating the "human factor", and in order to find a root cause and prevent similar events in the future, the way the subject flight crew, a "standard" company crew, has operated, should be extrapolated to all the pilots in the organization.

The investigating team opines that "<u>unusual</u>" malfunctions are feasible, which may require examination and analysis of the situation, for performing actions outside of the checklist, and/or even in contradiction to the checklist (as explained in paragraph 2.9.5). It is probable that the flight crew will refrain from doing them.

Hence, it is necessary to examine whether the operator's method of instruction, study, and assimilation of the manufacturer's NNC written policy (Boeing), and also included in the FCTM, which were adopted by the company and approved by CAAI, is indeed implemented in practice.

## 2.10 The landing in Goa

The landing in Goa was performed in excess of the maximum landing weight and with one engine inoperative. The investigating team found that the landing was conducted in accordance with the company's procedures, the manufacturer's publications and the judgement of the captain in command.

## 2.11 The teamwork

The crew work, as a team, was carried out openly and freely, enabling all parties involved to express their opinions.

The interviews carried out indicate that the crew teamwork, led by the captain in command, were conducted openly and inclusively.

## 2.12 Boeing publications

- ☒ In the manufacturer's publications (FCOM), **no fault resulting in fuel migration from the Center Tank to the Main Tank is mentioned**. Even in NNC FCOM such a fault does not appear clearly, although it was known to the manufacturer for several years.

  In addition, this fault neither appears nor is practiced by crews in flight trainer (simulator), since there is no way to generate such a fault.
- ☒ The investigating team found that the fuel system's 3 NNCs were not compatible with nor exhibiting the event's malfunction. The investigating team examined the factors that contributed to actions made by the crew:
  - The **"Fuel Imbalance" checklist** does not provide Main Tanks' fuel balancing (even by Crossfeed), as long as the Center Tank pumps are operating (there is no instruction to turn them OFF). Alternately, there is no "Note" stating that balancing is impossible when the Center pumps are operating (while there is such a note regarding fuel balancing by the Balance switch).

    In addition, the "Fuel Imbalance" checklist includes a "**closed**" list of conditions, which might indicate a **suspicion** of a fuel leak. This list is "limited" and might mislead the crew to assume that **these are the sole** potential causes for a suspected leak. In this incident, there were other indications of suspected fuel leakage, which were not taken into account by the staff, due to the fact that the above list is written in a restrictive and "closed" manner.

    *Note: In March 2022, while the investigation was still in process, the manufacturer has published a revision to the "Fuel Imbalance" checklist and responded to the fuel migration discrepancy.*

- The "**Fuel Disagree**" alert message **directs** the crew to deal with the **lower fuel quantity** Main Tank, and thus it is further fixating the erroneous approach of the troubleshooting. See Appendix 2 – FCOM NNC "Fuel Disagree":
  "One main tank is **abnormally low** compared to the other tank, and to the expected fuel remaining in the tank"
- While dealing with the "**Fuel Leak**" discrepancy at the stage of confirming a fuel leak (a difference of 500 kg within 30 minutes), the procedure was "**disrupted**" by the LH Scavenge pump activation (see Figure 3, which displays only LH Scavenge pump operation). See also flow chart of the "Fuel Leak" (U)NNC by the crew, as conducted in real time. See Appendix 3 FCOM UN-ANNUNICATED NNC "FUEL LEAK".
- The leak source in this event could not be detected per the "Fuel Leak" checklist (see explanation in paragraph 2.5).

The investigating team's assessment is that certainly the above 3 checklists are not optimally responding to the event's discrepancy, and **they may have contributed to the unnecessary engine shutdown by the crew.**

***Note: In the course of the investigation, a letter from Boeing has been received, indicating that the manufacturer is evaluating the above checklists and intends to consider revising them. As mentioned above, the "Fuel Imbalance" checklist has already been revised.***

☒ The investigating team found that the manufacturer publications' policy regarding usage of Synoptic display, does not include cases of "unusual" discrepancy (see Appendix 7).
The NNC Introduction and the FCTM guide the captain to: "**Assess the situation**" and "**Analyze the situation**", **before dealing with the malfunction**, whenever time is available, namely gathering information by all available means and from all available sources.
The investigating team thinks that additional clarification is required by the manufacturer in regard of using the Synoptic, in particular at "unusual" cases with unclear information, and/or noncompatible checklist.

☒ The manufacturer has revised the NCC Introduction to include performing "Analyze the Situation" prior to executing checklist actions (see Appendix 4).

## 2.13 Electronic Check List (ECL)

The ECL is intended to assist the pilot, by digitally displaying the required checks, without having to "search" them, as was the case with hard copy checklists.

The ECL is a complex tool and using it requires thorough familiarity and high competency. It also requires the user to understand its operation logic, to study it and practice extensively, to achieve comprehensive knowledge of all its "nuances".

Unlike the printed QRH, which can be used on scheduled flights for learning and training, the ECL is an integral part of the aircraft systems, and is difficult to learn and use while flying, because its operation might change the state of switches/valves, so that one cannot proceed to line items that were not yet performed, and/or OVRD actions are required for such lines.

In light of the above, there is an understandable apprehension among flight crews, who want to learn and use it in flight when there is no actual malfunction.

In addition, when training in the simulator, which is performed under a tight schedule, the emphasis is on practicing discrepancies, and does not leave enough time for training and practicing the ECL.

This situation contributes, in the opinion of the investigation team, to "locking" in a working method according to the "fault line" in EICAS and to "automatic navigation" for handling discrepancies by means of the electronic checklist.

During the subject event discrepancy, the flight crew transitioned to use the hard copy NNC (QRH). It may have stemmed from insufficient knowledge of the ECL and its operating logic, and mainly from insufficient confidence in using it.

The "Fuel Leak" checklist is fairly complex and includes multiple decision junctions (YES/NO), as a condition to accomplish actions and to obtain the confirmation "**Checklist completed**". This complexity, along with an "unusual" discrepancy and unclear fuel migration may have induced lack of confidence, which in turn caused the crew to "abandon" the ECL and switch to using the hard copy NNC (QRH), so as to be certain they are not making errors related to the NNC (they later returned to the ECL to complete the Deferred Items).

*Note: The investigating team, assisted by a qualified B787 instructor, has compared the ECL with the QRH and has not found any contradiction.*

The investigation team believes that systematic and thorough training, including providing options to practice the use of ECL (not on the plane), will contribute to the crews feeling comfortable operating it, even in emergencies where there is no time and no room to make mistakes, while building confidence and trust in this system.

Studying how this issue is handled by other operators, it was found that some operators are using desktop procedures trainers (ADT - Avionics Desktop Trainer **or** VAPT - Virtual Avionics Procedure Trainer **or** IPT - Integrated Procedures Trainer). This is a desktop computer, which contains computerized simulation of the cockpit and can be operated per various procedures, including FMC and ECL.

## 2.14 Communications

### 2.14.1 AHM vs. MCC communication

No evidence was found for a reporting via AHM system about EICAS messages concerning the fuel system malfunctions "Fuel Imbalance" and "Fuel Disagree". Checking with the manufacturer turned out that because these messages are not associated with specific maintenance messages, they are not monitored by the Central Maintenance Computing Function (CMCF) and therefore are not transmitted via AHM. The parameters reported by the system are set by the manufacturer (Boeing) and the operator (El Al) cannot independently modify them.

*Note: If an operator desires to have Advisory messages, it can approach the manufacturer for modifying the system configuration.*

In such case the MCC would be able to detect a problem in real time, report it internally to the OCC and also advise the flight crew regarding possible ways of action.

### 2.14.2 Flight Watch vs. OCC communication

The fuel parameters transmitted from the aircraft throughout the flight are Calculated values, not Actual values (Totalizer). The transmitted fuel quantity is compared to the flight plan fuel figures and if the difference exceeds 500 kg, a caution message will come on at the OCC systems. It is probable that transmitting the Totalizer fuel will provide, under certain circumstances, an early warning of an evolving fuel problem.

Each of the above methods has its pros and cons, and the operator can select its preferred method.

### 2.14.3 Communication with OCC and MCC

The flight crew did not communicate with neither OCC nor MCC throughout the flight (as stated in paragraph 1.1). It is important to conduct such communication, in view of the ability to provide real time consultation with other professional entities, such as company managers or the manufacturer.

The crew notified the OCC about the engine shutdown and the decision to land in Goa.

## 2.15 Monitoring the Crossfeed valve by the EAFR

Analysis of EAFR (DFDR) recordings has shown that the Crossfeed valve positions "Open" and "Close" are being recorded. The recorded parameters are: "**Eng_Crossfeed_Valve_Open_Ind**" and "**Eng_Crossfeed_Valve_Close_Ind**".

## 2.16 Preserving recorded data

Right after the Chief Investigator was notified of the event by the crew and at his request for retention of flight recorders' data (DFDR, CVR) for investigative purposes, a Logbook entry was opened by the PIC for downloading the data.

According to the procedure, the FWD EAFR was supposed to be disconnected (from power source), but due to a lack of attention, while running the engines, the EAFRs were plugged in, so that the CVR data were deleted from both recorders.

On 8.11.2021, a Logbook entry was made by a technician and the FWD EAFR CB was opened ("pulled out"), but at this time all the CVR data from the relevant event flight had already been deleted.

The permanent failure to disconnect (DFDR, CVR) from power source, immediately after landing of the aircraft in GOI and keeping it disconnected even while running the engines, was the reason for deleting all CVR data.

**Deleting the recorded data damaged the investigation of this incident.**

## 3. Conclusions

**3.1** The incident, which was initiated by "Fuel Migration", for a reason that was not fully clarified, from the Center Tank to the RH Main Tank, and from there to the RH Surge Tank, and spilled outboard the aircraft, that lead to the **wrong Engine shutdown** and to an emergency landing. The crew did not diagnose the situation, and acted as much as it could, according to the NNC, in accordance with the messages received. The NNC did not respond to this type of malfunction, and as a result, the crew concluded that there was a fuel leak on the left side of the aircraft, turned off the Left Engine, and made a deviation to make an emergency landing in the lane subfield, even though the engine was operating normally and there was no leak on the left side.

**3.2** The incident occurred following a combination of an "abnormal" fault, which their nature was unknown to the operator and its flight crew, that did not appear in the training publications, hence, is not learned and practiced, and apparently as a result, the flight crew misunderstood the source of the fault and misidentified it, while using the 3 checklists:
("Fuel Imbalance", "Fuel Disagree", " Fuel Leak"), which gave only a partial answer to understanding the situation and contributed to misleading the crew, which led to a logical but wrong diagnosis and to shutting down the engine on the side where there was no leakage (shut down of wrong engine). **It is highly doubtful whether under similar circumstances, another operator's crew would have acted differently.**

**3.3** A fuel system discrepancy characterized by inadvertent fuel migration from the Center Tank to the RH Main Tank, and from it to the RH Surge Tank ending in spillage overboard, has happened in the past on B787 aircraft, in 3 known, documented cases. No failed component was found in those cases and hence, the manufacturer (Boeing) has diagnosed it as an FOD problem. In this occurrence as well, the fuel system was inspected comprehensively, according to the AMM and additional instructions by the manufacturer (Boeing), but there were no findings indicating a failed component.
It is highly probable that there is a Latent Defect in the fuel system, which might cause fuel migration from Center Tank to a wing Main Tank. This latent defect can be, among others, in one of the valves or in the fuel system logic.

3.4 The company's policy for handling faults has gone a long way. The policy began with a method of locating, analyzing, and making a personal decision by the PIC, (not necessarily according to orderly and uniform process), and evolved to strict adherence to acting according to the checklist (with an emphasis on introduction of ECL), which reduces flexibility in analysis, understanding, searching for the correct way to handle faults (Analyze), and the captain's discretion. This policy only partially complies with the manufacturer's policy, as set out in the Introduction to NNC as well as in the FCTM.

3.5 The company's policy of adhering to the checklist and acting **only** in accordance with what is written in it, did not meet the reality test and in two cases a deviation from it (action contrary to the checklist) was made by the crew:

1. After an attempt to balance fuel, that failed due to the operation of a Center Tank O/J pumps, returning the switches to their original positions, i.e., closing the Crossfeed valve and stopping the Main Tank Boost pumps (See paragraph 2.9.6).
2. Determining that the Scavenge pump activation has disrupted the check of the source of the fuel leak, and therefore the leak is from the LH wing/engine (See paragraph 2.7).

The crew that acted contrary to the Checklist, after exercising discretion, subsequently received the operator's backing.

The contradiction in the operator's policy, which on the one hand defines absolute adherence to the checklist, and on the other hand responded (retrospectively), the actions of the team that included actions in violation of the checklist, leads to an unclear situation between allowed and forbidden.

The crew's concern of analyzing and inaccurate understanding of the malfunction, when a Fuel Imbalance message appeared, and the inability to balance the fuel, contributed to the difficulty in determining the correct course of action, combined with checklist(s) that did not address the fault.

3.6 In this complex event, no in-depth analysis of the situation was carried out and no complete and accurate identification of the fault was carried out **prior to beginning to act upon** (execution of the checklist). It is highly likely that the lack of analysis was due, among other things, to the concept of instruction, study and training by the operator, in which the pilots are encouraged to adhere to the checklist items, especially in aircraft with an EICAS system that "pops up" the ECL and ostensibly eliminates the need to delve into what is behind it.

Balance was not maintained between strict adherence to the checklist versus acting according to the publications and procedures, which guide to perform an analysis before dealing with the fault and determining the course of action

*Note: The manufacturer Boeing has lately released an NCC Introduction revision (March 2022), that includes performing the Analyze, in order to clarify its policy for correct handling of faults and includes the setting of a course of action (see Appendix 4).*

**3.7** The parts of the policy, which handle the **Analyze phase**, is missing from the operator's OM-A. This phase did not include examining all the data, alerts, and signs of a malfunction, and determining the course of action, before deciding to address it. The operator's policy should be adapted and be practiced in **simulator** training in order to improve the handling of malfunctions on scheduled flights.

A good example of post-fault analysis, in accordance **management** policy, is described in OM-A paragraph 8.3.20.1, detailing he use of forded, which is practiced and implemented by the operator.

**3.8** In the operator publications (OM-A), the handling policy of faults in general, and especially the handling of "abnormal" faults in particular, including the use of the Synoptic display, is not clearly defined in a way that will guide and support the crew to use all information sources available.

**3.9** A lack of knowledge and gaps has been identified at the operator, regarding the understanding of the fuel system, which is complex and has unique characteristics, including a variety of possibilities for malfunctions and for resolving them. These topics were only partially covered in instruction, training and simulator practice. It is important to narrow these gaps of knowledge.

**3.10** The method for monitoring in-flight fuel consumption in the operator's publications, is not defined properly, and might lead to a late detection of a fuel leak, due to relying on the Calculated parameter only, without examining the Totalizer data in comparing it to the flight plan.

**3.11** ECL learning and training gap was identified. there is no capability for self-practice (off airplane devices, such as procedures trainer with computerized emulation of the cockpit, which enables operating ECL procedures), in order to enhance flight crews' confidence in the ECL tool.

**3.12** The operator has a procedure for storing recorded data in the event of an accident and/or incident. The procedure was not implemented in this incident, and as a result important safety information was not available to the investigation team. There were previous events in which recordings have been "deleted".

**3.13** The three checklists ("Fuel Imbalance", "Fuel Disagree", "Fuel leak") are not worded optimally, **and might lead flight crews to erroneous actions** due to the incompatibility to event such as the one in this investigation.

**3.14** As per the "Fuel Leak" checklist, it is impossible to detect the leak source when the rate is less than 15 kg/minute or lower.

**3.15** Activation of the Scavenge pumps when fuel quantity in the Main Tank is relatively high is highly likely to impair the fuel leak test.

**3.16** The NNC Introduction's wording dealing with combined malfunctions and/or multiple system failures where the checklist is not fully compatible, might also be applicable to a single malfunction in a single system (as was the case in the subject event).

**3.17** The manufacturer's FCTM policy for using the Synoptic display, where it describes "unusual" cases of unclear discrepancy and incompatible checklist, is not providing optimal guidance for using it as a tool for gathering additional information (see Appendix 7).

**3.18** The flight crew was licensed and qualified to perform a flight in accordance with the law and the regulations.

**3.19** The maintenance records indicate that the aircraft was airworthy and maintained in accordance with the operator's regulations and procedures.

**3.20** Weight and balance of the aircraft were within the limits and as required

**3.21** EICAS Advisory messages, such as "Fuel Imbalance" and "Fuel Disagree" are not monitored in the AHM communication.

**3.22** The Totalizer information is not monitored by the OCC Flight Watch system, and thus it is difficult to track fuel status and get warnings on a potential leak and/or abnormal fuel consumption.

**3.23** Communication between the flight crew, OCC and MCC in the subject event was partial. Effective communication may support understanding and analyzing of discrepancies in general, and of "unusual" discrepancies in particular.

# 4. Safety Recommendations

**4.1** To revise the company's policy for dealing with malfunctions in general and "unusual" malfunctions in particular, in a manner which will meet the need to gather and analyze information, as defined in the manufacturer's and the company's publications.

**Responsibility:** Operator

**Recommended deadline:** December 31st, 2022

**4.2** To conduct dedicated training on the fuel system for the fleet pilots, with emphasis on the discrepancy in the subject event.

**Responsibility:** Operator

**Recommended deadline:** December 31st, 2022

**4.3** To revise the in-flight fuel consumption check procedure and include a definition of how it should be performed (by the Totalizer parameter or/and the Calculated parameter).

**Responsibility:** Operator

**Recommended deadline:** December 31st, 2022

**4.4** To act for enhancing the familiarity with the ECL and check feasibility for using an adequate, dedicated training aid for the fleet pilots, which will be available for self-training at any time.

**Responsibility:** Operator

**Recommended deadline:** May 1st, 2022

**4.5** To revise and improve the procedure for storing of flight recorders data (DFDR, CVR) in case of accident/incident, in a way which will ensure that the recordings will not be erased.

**Responsibility:** Operator

**Recommended deadline:** December 31st, 2022

**4.6** To revise the "Fuel Imbalance" checklist regarding the subject event malfunction, so that it provides an effective solution for the possibility of balancing fuel between the wing tanks (using Crossfeed). Alternately, to add a Note stating such action is impossible as long as the Center pumps are operating.

*Note: In the course of the investigation **the manufacturer has distributed a revision** which responded to the safety issue. This update was published in March 2022.*

**Responsibility:** Manufacturer

**Deadline:** Done

**4.7** To revise the "Fuel Imbalance" checklist, so that it does not include a limited and "closed" list of conditions and parameters which indicate a suspected fuel leak.
**Responsibility:** Manufacturer
**Recommended deadline:** June 1st, 2023

**4.8** To revise the "Fuel Disagree" checklist, so that it does not instruct and focus the crew on handling on the Main Tank with lower fuel quantity.
Note: In the course of the investigation the manufacturer has informed the investigation team that it intends to consider revising the checklist.
**Responsibility:** Manufacturer
**Recommended deadline:** June 1st, 2023

**4.9** To revise the "Fuel Leak" checklist, so that when the fuel leak source detection is checked for 30 minutes duration, the Scavenge pump activation might impair the check.
Note: In the course of the investigation the manufacturer has informed the investigation team that it intends to consider revising the checklist.
**Responsibility:** Manufacturer
**Recommended deadline:** June 1st, 2023

**4.10** To analyze the reasons of the several events of Fuel Migration from the Center Tank to the Main Tank while the Center O/J pumps are operating.
**Responsibility**: Manufacturer
**Recommended deadline:** June 1st, 2023

Sincerely

Gad Regev
Chief Investigator

Date: June 14, 2022 Ref.: 4000-0098-2022-0000193

# Appendixes

## 1. FCOM NON-NORMAL CHECKLIST – "FUEL IMBALANCE"



### [] FUEL IMBALANCE

Condition: There is a fuel imbalance between the main tanks.

Objective: To decide if a fuel leak is suspected. To balance fuel if a fuel leak is not suspected.

1 If an engine has low fuel flow and unusual engine indications, the FUEL IMBALANCE message may show due to engine damage instead of a fuel leak.

2 The FUEL IMBALANCE message may be caused by a fuel leak or a fuel imbalance.

3 A fuel leak should be suspected if one or more of the following are true:

The total fuel remaining on EICAS is less than the planned fuel remaining.

An engine has excessive fuel flow.

On PROGRESS page 2, the totalizer is less than the calculated fuel.

The TOTALIZER fuel is the sum of the individual tank quantities.

The CALCULATED fuel is the totalizer value at engine start minus fuel used.

Fuel used is calculated using the engine fuel flow sensors.

4 **If** a fuel leak is suspected:

**►►Go to the Fuel Leak checklist on page 12.22**

▼ Continued on next page ▼

▼FUEL IMBALANCE continued▼

5 The fuel balance system is inhibited (not available) if any of these occur:

A center tank pump is on

On the ground and one or both engines are running

In flight and the fuel jettison system is active, or the FUEL DISAGREE or FUEL QTY LOW message shows

6 Choose one:

◆Fuel balance system is **available**:

►►**Go to step 7**

◆Fuel balance system is **not** available:

►►**Go to step 9**

7 FUEL BALANCE switch . . . . . . . . . . Push and hold for 1 second

8 The fuel balance system may take up to 30 seconds to activate.

■ ■ ■ ■

9 FUEL BALANCE switch . . . . . . . . . . . . Push to Off

Ensure the ON light is extinguished.

10 FUEL CROSSFEED switch . . . . . . . . . . . . . . . . On

▼ Continued on next page ▼

**▼FUEL IMBALANCE continued▼**

11 Choose one:

◆**Left** main tank quantity is low:

FUEL L PUMPS
switches (both) . . . . . . . . . . . . . . . . . . Off

Do **not** accomplish the following checklists:

FUEL PUMP L AFT

FUEL PUMP L FWD

**►►Go to step 12**

◆**Right** main tank quantity is low:

FUEL R PUMPS
switches (both) . . . . . . . . . . . . . . . . . . Off

Do **not** accomplish the following checklists:

FUEL PUMP R AFT

FUEL PUMP R FWD

**►►Go to step 12**

12 **When** fuel balancing is complete:

FUEL L PUMPS and R PUMPS
switches (all) . . . . . . . . . . . . . . . . . . . . . . . . ON

FUEL CROSSFEED switch. . . . . . . . . . . . . . . Off

■ ■ ■ ■

## 2. FCOM NON-NORMAL CHECKLIST - "FUEL DISAGREE"



### [] FUEL DISAGREE

Condition: The totalizer fuel quantity and the FMC calculated fuel quantity disagree.

Objective: To decide if a fuel leak is suspected. To select the most accurate fuel value if a fuel leak is not suspected.

1 The FUEL DISAGREE message may be caused by a fuel leak.

2 A fuel leak should be suspected if one or more of the following are true:

The total fuel remaining on EICAS is less than the planned fuel remaining.

An engine has excessive fuel flow.

One main tank is abnormally low compared to the other main tank and to the expected fuel remaining in the tanks.

On PROGRESS page 2, the totalizer is less than the calculated fuel.

The TOTALIZER fuel is the sum of the individual tank quantities.

The CALCULATED fuel is the totalizer value at engine start minus fuel used.

Fuel used is calculated using the engine fuel flow sensors.

▼ Continued on next page ▼

▼FUEL DISAGREE continued▼

3 **If** a fuel leak is suspected:

►►**Go to the Fuel Leak checklist on page 12.22**

4 Select PROGRESS page 2.

Select TOTALIZER unless it is inaccurate.

5 ⚠ TOTALIZER or CALCULATED. . . . . . . . . . . . . . . . . . . Select the most accurate value

■ ■ ■ ■

## 3. FCOM UNANNUNCIATION NON-NORMAL CHECKLIST - "FUEL LEAK"



### Fuel Leak

Condition: A fuel leak is suspected for the reasons listed in the Additional Information section of this checklist.

Objective: To confirm there is a fuel leak. If confirmed, to isolate the leak to one of the following:
- Engine
- Main tank
- Center tank

1 A diversion may be needed.

2 FUEL BALANCE switch . . . . . . . . . . . . Push to Off

Ensure the ON light is extinguished.

3 FUEL L PUMPS and R PUMPS switches (all) . . . . . . . . . . . . . . . . . . . . . . . . .ON

4 FUEL CROSSFEED switch . . . . . . . . . . . . . . . . .Off

5 FUEL CENTER PUMPS switches (both) . . . . . . . .Off

The FUEL IN CENTER message may show.

6 **The following steps check for an engine or main tank leak.**

7 Record the main tank fuel quantities and the current time.

8 An engine/main tank leak is confirmed if one or both of the following are true:

Fuel spray is observed from an engine, strut, or wing

▼ Continued on next page ▼

▼Fuel Leak continued▼

A change in fuel imbalance of 500 kgs within 30 minutes or less

9 Choose one:

◆Engine/main tank leak is **confirmed**:

►►**Go to step 20**

◆Engine/main tank leak is **not** confirmed:

►►**Go to step 10**

10 Choose one:

◆FUEL IN CENTER message **shows**:

►►**Go to step 11**

◆FUEL IN CENTER message **is blank**:

Resume normal fuel management.

■ ■ ■ ■

11 **The following steps check for a center tank leak.**

12 FUEL CENTER PUMPS switches (both) . . . . . . . .ON

13 Select PROGRESS page 2.

14 Record the totalizer and calculated fuel quantities, and the current time.

15 A center tank leak is confirmed if the difference between calculated and totalizer increases by 500 kgs within 30 minutes or less.

▼ Continued on next page ▼

▼Fuel Leak continued▼

16 Choose one:

◆Center tank leak is **confirmed**:

►►**Go to step 17**

◆Center tank leak is **not** confirmed:

Resume normal fuel management.

■ ■ ■ ■

17 Continue to use all center tank fuel.

18 Verify that sufficient fuel is available in the left and right main tanks to complete the flight.

**Note:** If the FUEL DISAGREE message shows at any time, go to PROGRESS page 2 and select the TOTALIZER fuel quantity.

19 Do **not** accomplish the following checklist:

FUEL DISAGREE

■ ■ ■ ■

20 **An engine/main tank leak is confirmed. The following steps shut down the engine to stop an engine fuel leak.**

21 The affected engine is on the side where the fuel quantity decreased faster.

22 A/T ARM switch
(affected engine) . . . Confirm . . . . . . . . . . . OFF

23 Thrust lever
(affected engine) . . . Confirm . . . . . . . . . . . Idle

▼ Continued on next page ▼

▼Fuel Leak continued▼

24 FUEL CONTROL switch
(affected engine) . . . Confirm . . . . . . . . CUTOFF

25 APU selector
(if APU available) . . . . . . . . . . . . START, then ON

26 TRANSPONDER MODE selector . . . . . . . . . TA ONLY

27 Choose one:

◆FUEL QTY LOW message **shows**:

FUEL CROSSFEED switch . . . . . . . . . . . On

This ensures that all fuel is available to the running engine.

►►**Go to step 28**

◆FUEL QTY LOW message **is blank**:

►►**Go to step 28**

28 Choose one:

◆FUEL IN CENTER message **shows**:

FUEL CENTER PUMP switch
(on side with running engine) . . . . . . . ON

►►**Go to step 29**

◆FUEL IN CENTER message is blank:

►►**Go to step 29**

29 Plan to land at the nearest suitable airport.

30 Select PROGRESS page 2.

31 TOTALIZER . . . . . . . . . . . . . . . . . . . . . . . Select

▼ Continued on next page ▼

▼Fuel Leak continued▼

32 Choose one:

◆Landing using flaps **20**:

Tuning and control panel
GPWS FLAP OVRD . . . . . . . . . . . . . .OVRD

**Note:** Use flaps 20 and VREF 20 for landing and flaps 5 for go-around. Buffet may be felt with flaps extended.

Check the Non-Normal Configuration Landing Distance tables in the Performance Inflight-FCOM chapter or other approved source.

►►**Go to step 33**

◆Landing using flaps **30**
**(if performance allows)**:

**Note:** Use flaps 30 and VREF 30 for landing and flaps 20 for go-around. Buffet may be felt with flaps extended.

Check the Non-Normal Configuration Landing Distance tables in the Performance Inflight-FCOM chapter or other approved source.

►►**Go to step 33**

33 **The following steps check for a main tank leak.**

34 Select PROGRESS page 2.

▼ Continued on next page ▼

▼Fuel Leak continued▼

35 Record the totalizer and calculated fuel quantities, and the current time.

36 A main tank leak is confirmed if the difference between calculated and totalizer increases by 500 kgs within 30 minutes or less.

37 Choose one:

- ◆A main tank leak is **confirmed**:

  ►►**Go to step 38**

- ◆A main tank leak is **not** confirmed:

  ►►**Go to step 41**

38 The leak is not an engine fuel leak. The engine may be re-started.

39 For a long diversion, range may be improved by re-starting the engine and climbing.

**Note:** Do not balance fuel.

If the FUEL QTY LOW message shows at any time, do the FUEL QTY LOW checklist.

40 Do **not** accomplish the following checklist:

FUEL IMBALANCE

►►**Go to step 42**

41 The fuel leak was an engine fuel leak.

▼ Continued on next page ▼

▼Fuel Leak continued▼

35 Record the totalizer and calculated fuel quantities, and the current time.

36 A main tank leak is confirmed if the difference between calculated and totalizer increases by 500 kgs within 30 minutes or less.

37 Choose one:

◆A main tank leak is **confirmed**:

►►**Go to step 38**

◆A main tank leak is **not** confirmed:

►►**Go to step 41**

38 The leak is not an engine fuel leak. The engine may be re-started.

39 For a long diversion, range may be improved by re-starting the engine and climbing.

**Note:** Do not balance fuel.

If the FUEL QTY LOW message shows at any time, do the FUEL QTY LOW checklist.

40 Do **not** accomplish the following checklist:

FUEL IMBALANCE

►►**Go to step 42**

41 The fuel leak was an engine fuel leak.

▼ Continued on next page ▼

▼Fuel Leak continued▼

**Note:** All remaining fuel can be used for the running engine. Use normal fuel management. When the FUEL IMBALANCE message shows, do the FUEL IMBALANCE checklist.

After landing, when parked, pull the fire switch for the shut down engine. This ensures the spar valve stays closed on the ground.

42 Do **not** accomplish the following checklists:

AUTOTHROTTLE L

AUTOTHROTTLE R

FUEL DISAGREE

43 **Checklist Complete Except Deferred Items**

## Deferred Items

### Descent Checklist

Recall . . . . . . . . . . . . . . . . . . . . . . . . . . Checked

Notes. . . . . . . . . . . . . . . . . . . . . . . . . . . Checked

Autobrake . . . . . . . . . . . . . . . . . . . . . . . . . ___

Landing data . . . . . **VREF 20___ or VREF 30___, Minimums___**

Approach briefing . . . . . . . . . . . . . . . . Completed

### Approach Checklist

Altimeters . . . . . . . . . . . . . . . . . . . . . . . . . ___

▼ Continued on next page ▼

▼Fuel Leak continued▼

## Landing Checklist

Speedbrake . . . . . . . . . . . . . . . . . . . . . . . . ARMED

Landing gear . . . . . . . . . . . . . . . . . . . . . . . DOWN

Flaps. . . . . . . . . . . . . . . . . . . . . . . . . . . . **20 or 30**

■ ■ ■ ■

## Additional Information

Reasons that a fuel leak should be suspected:

- A visual observation of fuel spray
- The total fuel quantity is decreasing at an abnormal rate
- An engine has excessive fuel flow
- The FUEL DISAGREE message shows
- The FUEL IMBALANCE message shows
- The FUEL QTY LOW message shows
- The INSUFFICIENT FUEL message shows

## 4. Manufacturer's revision for conducting "Analyze"

Following is the revision to the Non-Normal Checklists introduced to the publications by the manufacturer, with an emphasis on conducting **"Analyze the Situation"** prior to actually executing the checklist actions.

**RH Checklist Instruction CI.2.11**

DO NOT USE FOR FLIGHT

787 Flight Crew Operations Manual

Checklist Instructions - Non-Normal Checklists

### Non-Normal Situation Guidelines Overview

This is a general overview of how non-normal situations should be conducted.

Consider maximum use of autoflight system to reduce workload, if available and appropriate. If flight directors are selected on, ensure the proper flight director modes are selected.

| Pilot Flying | Pilot Monitoring |
|---|---|
| Recognizes and announces the non-normal situation. Other pilot acknowledges. | |
| **MAINTAIN AIRPLANE CONTROL**<br>Ensure that the flight path is under control. | Monitor the flight path. |
| | **ANALYZE THE SITUATION**<br>Review all EICAS alert messages to identify the non-normal situation.<br>Prioritize alerts and recommend course of action. |
| Acknowledges and confirms the Pilot Monitoring's identification or recommendation. | |
| **TAKE THE PROPER ACTION**<br>Do the NNC memory items based on each crewmember's area of responsibility. | |
| Call for the appropriate NNC. | |
| | Completes the NNC. |
| Review all EICAS alert messages, and do other NNCs as needed. | |
| **EVALUATE THE NEED TO LAND**<br>Review options for diversion or continued flight. | |

# 5. Data preservation procedure in case of aircraft accident/incident

### 5.1 The OM-A paragraph 1.4.3 states:

Unless the Chief Investigator has approved otherwise, the PIC shall prohibit erasure of data recorded on a flight data recorder and a cockpit voice recorder in the event of an accident or incident having occurred which may be subject to mandatory reporting. This shall be done by switching off or disabling both recorders at the end of the flight (this may be done by Maintenance if access is not available to the flight crew) and making an entry in the ATL stating:

1. “PLEASE DOWNLOAD CVR AND DFDR”;
2. Time of landing; and
3. Time the flight recorders were disabled.

In addition, he shall file a Flight Safety e-Report explaining the request to download the data.

### 5.2 The OM-A paragraph 11.4.2 states:

**11.4.2 Notification and Reporting**

The question of whether an incident constitutes an Incident, Serious Incident, or Accident (collectively:

“Safety Occurrence”) can be answered by consulting the definitions of Chapter 11.2 "DEFINITIONS" above and the e-Report Safety Report Form (an air traffic incident, for example, may be either). The Safety Reporting Form provides the contact information and initial reporting procedures for filing a report.

Whenever a report to the Authority is prescribed (according to Chapter 11.4.3 - 9), it shall be dispatched according to the time limits and responsibilities as depicted in the following table. Flight and Cabin Safety Reports filed through the e-Report system are sent automatically to the CAAI, the Chief Investigator, and relevant parties within EL AL. The submitter shall receive confirmation of submission provided he has completed the Submitter Email field in the e-Safety Report.

Another option is to complete the paper form and send the form according to the information displayed on the top of the front page of the form.

### 5.3 AIPM 9-4 procedure:

**AIPM** - AMO Internal Procedures Manual

9-4 Incident / Accident – Cockpit Voice Recorder (CVR), Digital Cockpit Voice Recorder (DCVR) and Flight Data Recorder (FDR) Download Document

AVIONICS ENGINEERING PROCEDURES

EL AL

**9-4 Incident / Accident – Cockpit Voice Recorder (CVR), Digital Cockpit Voice Recorder (DCVR) and Flight Data Recorder (FDR) Download Document**

**9-4-1 General**

A. Once the Avionics Line Manager is notified of an Incident / Accident the Cockpit Voice Recorder (CVR), Digital Cockpit Voice Recorder (DCVR) and Flight Data Recorder (FDR) recording raw data is downloaded and saved in a safe place.

B. This procedure provides instructions for downloading, preserving and retaining the recorded aircraft data (CVR, DCVR and FDR) after an incident or accident.

**9-4-2 Procedure**

A. Raw data downloading is done in accordance with the applicable AMM.

B. The raw data is saved by the avionics shops in the AIR-GROUP server.

C. Access to the raw data, is subject to the approval of EL AL Operations Safety Officer (EAOSO).

### 5.4 GMM 31-31-00-00 procedure:

1. **Description and Operation**

1.1 <u>General</u>:

The 787 has two flight recorders, called Enhanced Airborne Flight Recorders (EAFRs).

EAFR combines voice, data link, and flight data recording into a single unit. One is located in the crown of section 41, just aft of the flight deck and the other in the crown of section 47, above the aft galley. The forward EAFR is connected to a Recorder Independent Power Supply (RIPS) that provides 70+1-7 minutes of battery backup power after primary aircraft power is lost. Although the RIPS is only intended to keep the Cockpit Voice Recorder (CVR) function active after airplane power is lost.

The characteristics of the 787 EAFR include the following:

- The flight data acquisition function (FDAF) is integrated into each EAFR; there is no separate Digital Flight Data Acquisition Unit (DFDAU) or Digital Flight Data Acquisition Card (DFDAC).

- Two identical recorders acquire and record mandatory flight deck audio, data link messages, and flight data. Legacy aircraft have a separate CVR for audio, DFDR for flight data recording, and may record data link (if installed).
- Each EAFR can record up to 4000 bytes per second. This is equivalent to 2048 twelve-bit words per second.

- The 787's recording system can record up to 2500 separate parameters,

1.2 Reason:

This procedure provides instructions for downloading the DFDR and CVR data from the EAFR after an incident, accident or for period reasonableness check and as per request from the following Authorized Personnel:

- Chief Investigator of Israel (Ministry of Transportation)
- EL AL's Flight Crew
- EL AL's Operations Safety Officer
- Avionics Engineer.

**2. Accomplishment instructions:**

2.1 Actions Based on Authorized Personnel Requests:

Once the Avionics Line Maintenance or the MCC is notified by the authorized personnel of DFDR or CVR downloading, their responsibility is to issue a Work Order to perform the following Tasks as described in Table 1.

| | Task | Maintenance Action | Request | Authorized personnel/Document |
|---|---|---|---|---|
| 1 | AMM DMC-B787-A-31-31-01-01A-520A-A. | Remove FWD EAFR from the aircraft as a serviceable and send the EAFR to electronic shop 560/15 | Remove DFDR and CVR for investigation | Chief Investigator |
| 2 | AMM DMC-B787-A-31-31-00-09A-1108-A (ITEMS A-C) and accomplish item 2.3-2.4 by sending data to Ground Network. | Download EAFR Flight Data File using airplane network | Download or remove DFDR data. | Flight Crew/Operations Safety Officer |
| 3 | AMM DMC-B787-A-31-31-01-01A-520A-A. | Remove FWD EAFR from the aircraft as a serviceable and send the EAFR to electronic shop 560/15 | Remove CVR for investigation | Flight Crew/Operations Safety Officer |
| 4 | AM M DMC-B787-A-31-31-00-09A-1108-A (ITEMS A-C) and accomplish item 2.3-2.4 by sending data to Ground Network. | Download DAFR Flight Data File using airplane network | Download EAFR Flight Data File using airplane network | Avionics Engineer |

According to the procedure, a demand by the Chief Investigator is mandating removal/disconnection of one EAFR, which includes DFDR data and CVR data. In the subject event, the technicians on site have performed the Table's Task 4 instead of Task 1, and also did not pull out the EAFR circuit breakers promptly after the landing in Goa. This has eventually led to erasure of all CVR data. After the aircraft arrived in Israel, the Table's Task 3 was performed, but by now it was too late and no CVR data were found.

## 6. Procedure for pulling out circuit breakers in case of accident/incident

OI.2.1

ELAL

737 Flight Crew Operations Manual

### Accident / Incident

Condition: Involvement in an Accident or Serious Incident.

Refer to definitions in OM Part A, Chapter 11.2.

1 CVR . . . . . . . . . . . . . . . . . . .Switch off or disable

**737-800**
VOICE RCDR circuit breaker (P18-2:D7) . . Pull

**737-900**
VOICE RCDR circuit breaker (P18-2:D6) . . Pull

**777, 787**
Access is not available to the flight crew. Ask Maintenance to disable the CVR.

2 Make an entry in the ATL with instructions to download the CVR and DFDR.

See instructions in OM Part A, Chapter 1.4.3.

3 Report. . . . . . . . . . . . . . . . . . . . . . . . . . . .File

Refer to OM Part A, Chapter 11.4.2 for reporting requirements.

**Note:** Be sure to file all required reports. Multiple reports and reporting methods may be required, depending on the nature and location of the occurrence.

**6.1 OM-A procedure 8.3.17.1 states:**

**8.3.17.1 General**

All breakdowns or malfunctions of electrical equipment in the cabin shall be immediately reported to the flight crew. Cabin crew members shall never reset circuit breakers without prior approval from the flight crew. See CFSM 2.51.

**6.2 OM-A procedure 8.3.20.1.4 states:**

**8.3.20.1.4 Policy on the Handling of Abnormal Situations**

**Circuit Breakers**

For circuit breaker operation on the ground, in flight and for specific circuit breaker restrictions and procedures, refer to the respective OM Part B.

**6.3 OM-A procedure 8.6.1 states:**

**8.6.1 Minimum Equipment List (MEL)**

Before Commencing Taxi

If a failure occurs after the doors are closed but before taxi has commenced, perform the relevant non-normal checklist (as applicable). If the failure persists, continuing the flight is allowed in accordance with the MEL and the DDG, subject to the following requirements:

1. All DDG Operational and/or Maintenance items shall be applied;
2. Maintenance procedures are limited to switching off a system, pulling/collaring a circuit breaker, and placarding. These may be performed by the crew, only after consulting with maintenance. Any other maintenance procedures may only be performed by maintenance personnel;
3. The FOO shall be notified, and he shall check for any operational restrictions;
4. Enter a failure in the ATL before continuing the flight.

## 7. FCTM policy regarding synoptic display, paragraph 1.6 states:

**Synoptic Display**

Synoptic displays are provided as a means of assisting the flight crew in rapidly understanding the status of the airplane systems. However, crews **should not rely solely** on the displays for determining airplane status. Synoptic displays should only be used **as necessary to get the desired information** and then turned off. The clarity and simplicity of displayed information **enable the flight crew to obtain necessary information from a brief scan.**

Note: Reference to synoptic displays or maintenance information is not a requirement during the accomplishment of crew procedures.

If the flight crew elects to use synoptic displays in conjunction with accomplishment of procedures, they must assure no distraction from the intended task results. This is particularly true when accomplishing non-normal procedures. Under certain conditions, system faults can result in missing synoptic information. Therefore, decisions regarding non-normal situations should be based on EICAS messages and other flight deck effects and indications. In every case where a non-normal procedure results in a need for memory items, they should be completed before selecting a synoptic display. Accomplishment of necessary procedures should take priority over use of synoptic displays.

## 8. 787-FTD-28-18001

# FLEET TEAM DIGEST

| 787-FTD-28-18001 | | |
|---|---|---|
| **Issue Title** : Cracked Fuel Feed Tubes | | |
| **Airplane Model** | **ATA** | **Minor Model(s)** |
| 787 | 2822-21 | -8,-9,-10, |
| **Other Model(s)** | **ECCN** | |
| | 9E991 | |

| **Originated Date** | **Last Revised Date** | **Created On** |
|---|---|---|
| 12/15/2018 | 09/02/2021 | 08/27/2021 |
| **Estimated Completion Date** | **Next Update Date** | |
| 12/16/2022 | 12/10/2021 | |

## 9. 787-FTD-28-16004

**Fleet Team** Digest 787

View Article Summary

**BOEING PROPRIETARY**



View Previous Revision
Changes below shown in blue.
Double-click changes to view previous text.

| 787-FTD-28-16004 | | **ATA:** 2822-05 | **Last Revised:** 03-NOV-2016 |
|---|---|---|---|
| **Issue Title:** Boost Pump Housing Discharge Check Valve - Broken Spring | | | **Originated:** 02-AUG-2016 |
| **Airplane Model:** 787 | **Minor Model(s):** -8, -9 | **Other Models:** no other models applied to issue | **ECD:** |
| **Attachments/Illustrations:** Title(s) in this section are selectable attachments. | | | |
| **References:** Component Maintenance Manual (CMM) 28-24-40 | | | **Issue Status:** Closed |