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

Safety Investigation Final Report

Serious Incident File No. 33-18

- TAKEOFF WITH WRONG WEIGHT PARAMETERS IN THE FMC -

Date	**29.3.2018**
Aircraft	**B-787-9**
Registration	**4X-EDB**
Location	**Ben Gurion Airport**

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.

The sole objective of the investigation of an accident or incident under these Regulations is the prevention of future accidents and incidents. It is not the purpose of such an investigation to apportion blame or liability.

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 miss-understanding, the original report in the Hebrew language is taking over.

Glossary

ATM – Assumed Temperature Method
CRM - Crew resource management
CCD - Cursor Control Device
CCS - Cursor Control Selector
CVR - Cockpit voice recorder
CDU - Control Display Unit
CG - Center of Gravity
CG MAC% - CG expressed in % Mean Aerodynamic Chord
EAFR - Enhanced Airborne Flight Recorder
EICAS - Engine Indication and Crew Alerting System
EFB -Electronic Flight Bag
FMC - Flight Management Computer
FIXED DERATE – TO/TO1/TO2
FLAR - Flight Log and Aircraft Release
HUD - Head-Up Display
MFD - Multifunction Display
MFK - Multifunctional Keypad
MCP - Mode Control Panel
MAC - Mean Aerodynamic Cord
OPT - Onboard Performance Tool
OMA - Operations Manual
PF - Pilot Flying
PM - Pilot Monitoring
PIC- Pilot In Command
QRH - Quick Reference Handbook
TPR - Turbofan Power Ratio
TOW - Takeoff Weight
V1 - Takeoff Decision Speed
Vr - Rotation Speed
V2 - Takeoff Safety Speed
Vref - Reference Speed
Vmu - Minimum Unstick Speed
Vzf - Zero Flaps Maneuver speed
ZFW - Zero Fuel Weight

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Summary

On March 29, 2018 an El Al Boeing 787-9 departed Ben Gurion airport, near Tel Aviv on a scheduled passenger flight, LY 027, to Newark Airport, New Jersey with 282 passengers and 18 crew members on board.

While the crew reviewed the cruise performance during climb, the captain noticed that the computed optimum cruise altitude was significantly higher than planned. When looking for the cause he found out that the ZFW figure, in the Flight Management Computer, was 40 tons lower than the correct weight. The crew corrected the error.

The captain immediately realized that the takeoff was made based on performance parameters calculated for a wrong weight. He concluded that it was a serious event, contacted the company's control center, reported the error, requested that the fleet manager and the director of flight operations be notified and requested the latter to report the event to the Chief Investigator.

The event was reported to the Chief Investigator just before the aircraft landed. With the assistance of the fleet manager, he contacted the crew who were in New York. Upon realizing the severity of the event, the Chief Investigator decided to launch an investigation and informed the NTSB, Boeing and ICAO.

Subject Aircraft

1. Factual Information

1.1 Flight History (Israel local time)

❖ Background

On Thursday, 29-3-2018 at 01:49 a.m. a Boeing 787-9, registration 4X-EDB, operated by El Al Israel Airlines, took off on a scheduled passenger flight from Ben Gurion airport (TLV) near Tel Aviv to Newark airport (EWR) near New Jersey.

A double air crew was assigned to the flight, including a pilot in command (PIC, “Cap1” below), an additional captain (“Cap2”) and 2 first officers (“FO1” & “FO2”). FO1 was on a check ride, following completion of the conversion course from the 767 fleet. Cap1 acted as the checker. Cap2, who has recently completed a conversion course from the 737 fleet, was on an Atlantic “Route Qualification” flight (checkout for special routes). FO2 has recently completed a conversion course from the 767 fleet and this was his second regular line flight since. Scheduled departure time was 01:00 and the crew pick up time was set for 22:30, 2.5 hours before the scheduled departure, as is the norm at the 787 fleet.

According to ELAL, the flight was a “holiday flight”. Family members accompanied some of the crewmembers. His wife accompanied Cap2, his wife, baby boy joined FO1, and his two daughters joined FO2. Cap1 was flying singly.

The airplane was late on its previous flight arrival to TLV from Hong Kong. Due to the delay, El Al operations control center decided to delay flight 027’s departure time by 15 minutes and the crew pick up time was rescheduled accordingly to 22:45.

<u>Note</u>: Airport closure time for take offs due to noise limitations (“night curfew”) is 01:40.

The crew convened at the operations control center briefing room and only then, Cap1 became aware that the flight is a check ride for FO1 and a “route qualification” flight for Cap2.

FO1 was assigned to act as PF for the check ride and conducted the preflight briefing.

Dispatch documentation planned an estimated Zero Fuel Weight (EZFW) of 168,434 KG and estimated takeoff weight (ETOW) of 236,809 KG. Fuel quantity determined by the crew was exactly per the plan – 68,756 KG (Planned fuel quantity for takeoff was 68,375 KG, following a planned consumption of 381 KG of fuel for 20 minutes taxi).

Cap1 requested the OCC duty manager to obtain an approval for takeoff after airport closure time. After some time the crew were informed that takeoff was permitted until 02:00 local time.

Cap1 signed on the dispatch papers and the crew left for the gate at Terminal 3 after the captain has briefed the cabin crew. Since at their arrival to the terminal the airplane has not yet landed, the crew went to wait at the lounge.

The airplane reached the gate at 00:18 with 268 passengers on board.

- **Flight Management Systems preparation for flight**

The flight and cabin crew boarded the aircraft at about 00:50LT, 25 minutes prior to the revised departure time, while the a/c was still being cleaned, serviced, loaded and refueled. The final load sheet, Version 01 (“closed flight”) was sent to the a/c already when the crew entered the cockpit.

Cap1 and FO1 entered the cockpit and began preparations for flight. Cap2 was requested to, reviewed the aircraft technical log (ATL) and updated Cap1. FO2 performed a walk around and checked the crew rest compartment.

Cap1 and FO1 began the preflight procedure. Concurrently Cap1 was somewhat occupied with “service passengers” (family members of active crewmembers).

FO1 conducted initial, partial preparation of takeoff data on his OPT application, using the planned Zero Fuel Weight obtained from the flight plan and weather data from the ATIS. FO1 entered the planned weight in the ZFW field.

The final load sheet was brought to the cockpit prior to initiating the FMC preparations. Cap1 & FO1 reviewed the form together, found out that the ZFW has increased by 170 KG, and was now 168,604 KG. Cap1 declared “increase of 200 KG”. At this stage, there were no data entries on the “PERF INIT” page. Cap1 entered the ZFW figure, concurrent with its readout from the form. Cap1 mistakenly entered ZFW of 128.6 Tons instead of 168.6 Tons. He immediately noticed his error, stated it in the cockpit and (supposedly) made a correction. Actually, the wrong weight figure remained in the ZFW field. Cap2, who at the time sat at the observer seat heard Cap1 mention his error, saw him making a correction but from where he sat, did not see the new figure entered into the system. FO1 was not aware of the move, did not hear Cap1 mentioning his error and therefore did not follow the alleged correction.

Cap1 updated the required fuel to 69 tons, corresponding to the slight ZFW increase, and informed the ground crew (200 KG increase over the planned amount).

Cap1 signed the load sheet form and few minutes afterwards the station representative arrived and picked up the signed form.

Cap1, acting as PM, continued to feed data to the a/c systems.

After refueling completion, a technician boarded the cockpit and submitted the Fueling form to the crew for signing. FO2 who was standing at the cockpit entrance checked and signed the form. Few minutes later, the maintenance crew chief came in and let the captain sign the flight release in the FLAR.

FO1 checked the FMC after Cap1 completed its preparation, but did not notice the ZFW error in the PERF INIT page.

Cap1 and FO1 made performance calculations using OPT, each on his own iPad. Both of them entered TO in the thrust selection field, without Derate (ATM only), in accordance with the fleet policy for takeoff weights higher than 220 tons.

The crew copied ZFW & TOW values from the CDU. Cap1 copied both figures. FO1 only copied the TOW of 197.5 tons, since he previously entered the planned ZFW. He did not revise it at this point.

Cap1 mistakenly entered a temperature of 16 Deg. at the OPT, while actual temperature was 21 Deg. FO1 commented about it and Cap1 corrected it. Cap1 entered a takeoff weight of 197.6 Tons (rounded the figure up). FO1 noticed it and adjusted his figure accordingly. While doing so, FO1 noticed that the margin between TOW & ZFW on his OPT does not make sense (the ZFW was based on planning data and was approximately correct, while the TOW copied from the FMC was wrong, too low by 40 tons, hence the small difference between them did not make sense to him). FO1 associated it with not revising his OPT data from the FMC. He said that something was strange with his calculation, but did not state what it was. FO1 copied the wrong ZFW as seen on Cap1's OPT screen. Both active crewmembers made concurrent calculations and compared their results. Cap1 entered the takeoff speeds and thrust setting into the FMC & MCP, according to the computation results.

The crew continued preparation for flight. The doors closed at 01:34; the crew performed the Before Start Procedure and then the Before Start Checklist. At this point FO1 noticed that the Seat Belts Signs switch was in the OFF position and recalled that he did not sign off the fueling form. FO2, who was at the cockpit at that time said that he signed it and the switch was set to AUTO.

- **The flight**

Engines start and taxiing proceeded normally, considering the approval for takeoff until 02:00.

The a/c lined up from intersection E onto runway 26 at 01:49. After getting takeoff clearance, FO1 increased thrust, pressed TOGA and began takeoff roll.

Upon reaching the rotation speed (Vr) the captain called "Rotate". FO1 began rotating. Pulling on the control column, he felt that the a/c response was sluggish and "more stick" was required to lift the a/c off the runway and bring it to the takeoff reference line on the HUD. He also felt that it took a relatively long time until Cap1 called "Positive Rate". Cap1 raised the landing gear when initial climb rate was established and the climb proceeded as usual.

After climbing through 10,000 feet, Cap2 went out to the crew rest compartment while FO2 remained at the cockpit area making various arrangements.

While climbing through approximately 20,000 feet, the crewmembers conducted cruise performance check and were surprised to find out that the FMC computed optimum cruise altitude was about 38,000 feet. This figure seemed unreasonable, because on long-range flights, the initial optimum cruise altitude is typically about 34,000 feet, and the initial cruise altitude is set accordingly.

Checking data at the PERF INIT page, the crew discovered a 40 tons ZFW error, which led to a 40 tons error in the a/c gross weight. Cap1 corrected the mistake.

Cap1 immediately realized the severity of the event and its potential risk – as they made their takeoff using performance parameters calculated for a weight substantially lower than the actual weight.

Cap1 asked FO2 to summon Cap2 to the cockpit for a debriefing. Since Cap2 was already asleep, Cap1 cancelled his request. FO2 also retired for rest.

Cap1 contacted OCC and requested that the fleet manager and director of flight operations be informed. Director of flight operations was not available and was notified later on.

Cap1 & FO1 remained in the cockpit and conducted a preliminary debriefing. Among other things, they discussed their fitness to continue the flight in view of the “startling” event. They concluded that they are fit to continue. The other crewmembers entered the cockpit after about 4 hours and the crew conducted a thorough debriefing.

Before descent, Cap1 & FO1 discussed their mental fitness to conduct the approach and concluded that they are fit. The approach was uneventful.

After engine shut down, the crew pulled out the EAFR circuit breaker and entered a pilot report to download the recorded data for analysis.

After the flight closure, Cap1 talked with the fleet manager and subsequently filled and sent a computerized incident report.

1.2 Personnel

Captain 1 (PIC)

- 52 years old.
- 23 years with the company, 18 as captain. First qualified as check airman in 3/2004.
- Converted to the 787 fleet in February 2018 and qualified as checker in the fleet.
- Pilot license: ATPL.
- 24,800 flight hours total, of which 15,000 at El Al on 757, 767, 742, 744, 777, 787 aircraft.
- Captain flight hours on Boeing 787: 186.
- Valid proficiency check, date 16-2-2018.
- Valid medical certificate until 1-9-2018.

Captain 2

- 58 years old.
- 16 years with the company, 7 as captain.
- Pilot license: ATPL.
- 9,970 flight hours at El Al on 767, 737, 757, 787 aircraft.
- Captain flight hours on Boeing 787: 80.
- Valid proficiency check, date 27-2-2018.
- Valid medical certificate until 15-12-2018.

First Officer 1

- 33 years old.
- 3 years with the company.
- Pilot license: ATPL.
- 4,176 total flight hours, of which 1,176 at El Al on 767, 787 aircraft.
- Flight hours on Boeing 787: 40.
- Valid proficiency check, date 24-2-2018.
- Valid medical certificate until 24-9-2018.

First Officer 2

- 47 years old.
- 3 years with the company.
- Pilot license: ATPL.
- 10,112 total flight hours, of which 2,159 at El Al on 767, 787 aircraft.
- Flight hours on Boeing 787: 80.
- Valid proficiency check, date 18-2-2018.
- Valid medical certificate until 2-8-2018.

1.3 Aircraft data

- Aircraft model Boeing 787-9.
- Year of manufacture: 2017.
- Serial number: 42117.
- 2 Rolls-Royce Trent 1000 Package C engines, thrust 74,400 Lbs. each.
- Valid Certificate of Airworthiness issued by CAA-I.
- Maintained by El Al.

1.4 Ben Gurion airport weather

- **General**

  Weather was fair, light winds from South/South-West, good visibility, temperature of 21 Deg.

- **Take off weather (UTC time)**

  LLBG 282250Z 19008KT CAVOK 21/16 Q1002 TEMPO 28016G26KT

1.5 Ben Gurion airport data

- **General**

  Ben Gurion International Airport, near Tel Aviv – TLV/LLBG.

  Coordinates 32° 00.6' N, 034° 53.1' E.

  Magnetic deviation 4 Deg. E.

  Elevation 134 feet above sea level.

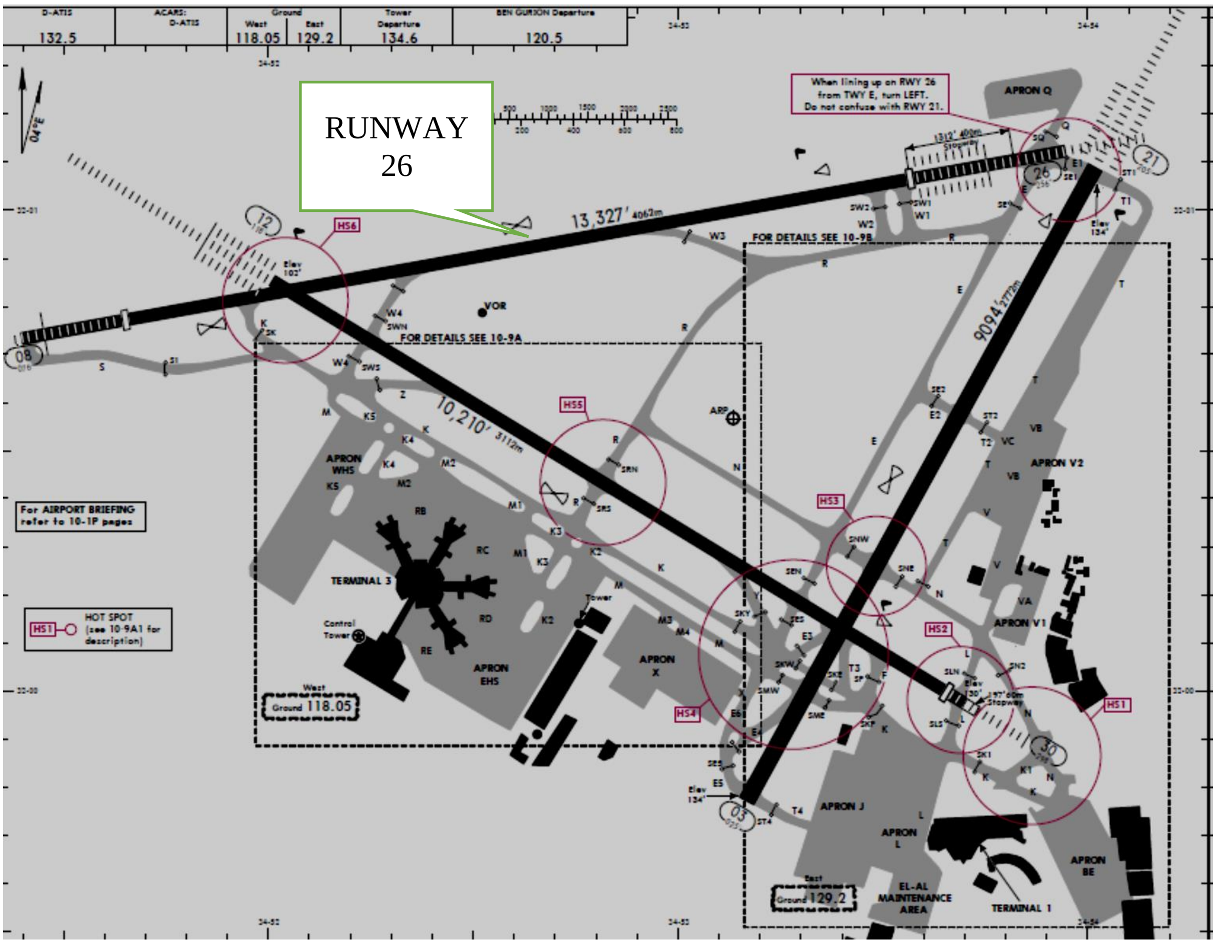
- **Runways – Asphalt** (Length & Width, in Meters)

  Runway 03-21: 2,772 × 60 meters.

  Runway 12-30: 3,112 × 45 meters.

  Runway 08-26: 4,062 × 45 meters.

❖ **Ben Gurion airport diagram**



1.6 Recorders & a/c relevant systems

1.6.1 EAFR

- B787 a/c have 2 units recording voice & flight data.
- The combined unit is named EAFR - Enhanced Airborne Flight Recorder.
- Manufacturer – Rockwell Collins.
- Model – EAFR 2100.
- Data recording duration – 25 hours.
- Voice recording duration – 2 hours.
- One unit is installed at the a/c forward area near door L1 and the other at the aft part near door L4.

1.6.2 EFB Class I

El Al flight crews are using iPad device as EFB Class I. The device contains all relevant aircraft manuals, OPT application for performance calculations, JeppFD-Pro app. for airport plates and navigation maps, EFOS app. for qualifications monitoring & management, flight reports, logbook, literature, forms and additional apps, including backups for essential apps.

1.6.3 EFB Class III

B787 a/c are equipped with EFB Class III, which includes a screen at each pilot's side, enabling the usage of a "moving map" app. (airports ground navigation), navigation aids, documents management and additional pilots' apps. The system includes the OPT app. for execution of performance calculations. Basic parameters for computation (QNH, OAT, T/O RWY, GW, and Origin) are transferred directly from the FMC. El Al policy is to use the OPT app. of the iPad and not the app. installed in the EFB.

1.6.4 OPT

Boeing's Onboard Performance Tool app. is installed on all pilots' iPads and on the EFB, is managed by flight operations engineer and is updated from time to time. The app. provides takeoff performance calculations, climb performance after takeoff and landing performance for dispatch & enroute. The app. contains all a/c models in the El Al fleet, all relevant airports and MEL & CDL.

The ZFW figure must be entered, in addition to the TOW figure, for computing takeoff performance on B787-9 a/c.

1.6.5 Takeoff Data Card/Bug Card

- Pilots for recording takeoff parameters and for quick reference use takeoff Data Cards.
- The card may be presented digitally or in hard copy.
- Takeoff Data Card is commonly used in many airlines. It is not included in El Al's operating procedures (except at the 767 fleet, in hard copy format).
- Following a safety event in 2012 in which an El Al 767 a/c took off with erroneous takeoff parameters, the then director of flight operations decided to introduce usage of the Takeoff Data Card. Implementation was postponed until equipage with iPads and eventually was not executed.

1.6.6 Flight Management Computer (FMC)

- B787 a/c have a “Common Computing Resource”.
- The common computing resource contains a Flight Management Function (FMF), which includes 3 flight management apps called Flight Management Computer (FMC).
- At all times one FMC app is active, while the other two are for backup.
- Access to the FMC, entering data and reading it, are done by means of a Control Display Unit (CDU).
- On 787 a/c, the CDU is an interactive unit, presented on a multifunction display (MFD).
- Entering data to the CDU is by means of a multi-function keyboard (MFK).
- Selecting a line for entering to the CDU can be done in 2 ways:
  - ✓ By means of a Cursor Control Selector (CCS).
  - ✓ By means of a "mouse" - Cursor Control Device (CCD).

1.6.7 Trim for takeoff

Precise trimming of the horizontal stabilizer for takeoff is of high safety and operational importance. The trim value is a result of a/c weight, center of gravity (represented by CG MAC% - location of center of gravity over the wing mean aerodynamic chord, in %), flaps setting and engines’ thrust. The trim value for takeoff is computed by the FMC according to calculated gross weight; CG entered by the crew, selected flaps setting and calculated engines’ thrust for takeoff.

The load sheet form presents trim values according to takeoff weight & CG, for various flap settings and Thrust Derate.

1.6.8 Engines thrust for climb

B787-9 a/c use the calculated takeoff thrust up to the selected transition altitude to climb power – CLB TPR. At El Al, the transition altitude is 1,500 feet AGL. The default at the B787 fleet is to use the climb power computed by the FMC. Selecting engines’ thrust for takeoff without Derate (TO) will result in full CLB power. The power for climb depends on the pressure altitude and the total air temperature (TAT) and does not depend on a/c weight.

1.6.9 Receiving data via data link

- B787 a/c can receive data via a data link from company headquarters, control units and other entities.
- Data link parameters available are (depending on the infrastructure):
  - PERF INIT
  - TAKEOFF DATA
  - WIND DATA
  - DESCENT FORECAST
  - ROUTE
  - ALTERNATE LIST
  - ALTERNATE WEATHER.
- Current EL AL data link infrastructure does not support performance and speeds data uplinks.
- The crew requests data by hitting the "Request" prompt adjacent to the desired parameter (provided the flight be properly initialized).
- The data are sent to the a/c after some time and a message is received.
- The parameters are mostly “Pending", meaning that the crew has to acknowledge and activate them.
- For instance – Following flight initialization the crew performs "Route Request". When the route is sent to the a/c, the crew receives a message. They should hit LOAD (or, if the result is not as desired, hit PURGE), then enter ACTIVATE, followed by EXECUTE.

Performance data can be requested similarly. PERF INIT & Takeoff Data parameters uplinked and displayed in the appropriate fields, and the crew should choose either ACCEPT or REJECT. Nevertheless, the crew can modify them later on.

1.6.10 Flight envelope protection in the flight control system

B787 a/c have a “Fly by Wire” flight control system with high redundancy. Pilot’s inputs via conventional control column and pedals are converted to electronic steering commands to the flight control surfaces. The system has several protections against exceeding the flight envelope, including:

- ☒ Protection from tail strike during takeoff and landing (TSP).
- ☒ Stall protection.

These protections are not absolute and can be overridden by the pilot.

1.6.11 Flap maneuver speeds

- Flap maneuver speeds are displayed on the airspeed indicator as green lines (Bugs), and the corresponding flap positions are displayed beside these lines. When the a/c is at a particular flaps setting, the area above the corresponding line represents the airplane's "Full Maneuver Capability", i.e. at least 40 Deg. of bank, consisting of 25 Deg. and an overshoot of 15 Deg.
- Maneuver speed for a flap setting varies solely according to the a/c weight, other parameters are not considered.
- Flaps retraction after takeoff is done with the a/c accelerating thru the maneuver speed of the current flap setting before reaching the next flap setting. At the interim stage, between the two lines, the a/c has "Adequate Maneuver Capability", i.e. at least 30 Deg. of bank, consisting of 15 Deg. and an overshoot of 15 Deg.
- The narrowest theoretical maneuver margin is 1.24"g", upon retracting flaps from 1 to UP.
- The actual maneuver capability is typically better than the above values and represented by the Amber Band – The top & middle of the band are representing full maneuver capability & adequate maneuver capability, respectively.

1.6.12 Rotation and risk of tail strike with 2 engines and engine out

- Takeoff speeds are based on a/c controllability, stall margin and tail strike prevention.
- Proper takeoff technique requires initiation of pulling the control column at the rotation speed, in order to achieve a specific pitch attitude at a steady rate. The eventual pitch attitude becomes shallower as engines' thrust is lower.
- Takeoff safety depends on rotating at the correct speed and at the appropriate rate. Rotation at a slower speed (or at a rate too high) might cause tail strike.

1.6.13 Flight Crew Operations Manual (FCOM)

- The a/c is operated according to instructions in the FCOM.

1.6.14 Normal Checklist

- The crew is using the normal checklist to verify that the a/c systems are ready and properly configured for each stage of the flight.
- Checklist callouts are made after the required tasks are accomplished.
- B787 a/c have an electronic checklist.
- Electronic checklist has "sensed" stages, which are identified and checked off automatically by the a/c, and "open loop" stages, which the crew must check, call out and mark as accomplished.
- The general instructions for using the normal checklist are stated in the Checklist Content section of the Checklist Instructions chapter in the QRH. The manufacturer has set the following criteria for items to be included in this checklist (quote):
  - items essential to safety of flight that are not monitored by an alerting system, or
  - items essential to safety of flight that are monitored by an alerting system but if not done, would likely result in a catastrophic event if the alerting system fails, or
  - items needed to meet regulatory requirements, or
  - items needed to maintain fleet commonality between the 737, 747-400, ,777 ,767 ,757and 787, or
  - items that enhance safety of flight and are not monitored by an alerting system (example the autobrake), or
  - during shutdown and secure, items that could result in injury to personnel or damage to equipment if not done
- Takeoff speeds are among the parameters that the crew is required to call out during the Before Start Checklist.
- There is no requirement to check or to call out the takeoff power (TPR).

1.7 Organization and management

1.7.1 El Al 787 fleet

- El Al's 787 fleet is new. The first El Al B787-9 commercial flight was conducted on 12-9-2017.
- The fleet was originally intended to be integrated with the 777 fleet (mixed operation), where 777-qualified pilots will go through a CAAI-approved "differences course". Eventually a separate 787 fleet was established for non-professional reasons, and pilots from various fleets were, and are currently converted to it.
- 777-qualified pilots go through a "differences course"; pilots from other fleets go through a standard conversion course.
- Being a new fleet, all its pilots have little experience on the B787; some of the first officers are generally inexperienced.
- One of the factors identified during the fleet establishment was a substantial difference of age and experience between captains and first officers ("hierarchy gradient").
- During fleet establishment, El Al conducted risk management processes in which various factors were assessed as well as the associated risks, probability of safety events and mitigation measures.
- Conversion courses for the 787 fleet include short CRM workshops in order to cope with the hierarchy gradient issue.

1.7.2 787 "same type" as 777 definition for pilots qualification

- The EU's aviation safety organization EASA, in its decision on 16-5-2014 has recognized the three series of the model B787 as variants of the model B777 for the purpose of pilot license endorsement.
- This approval is in EASA's document "EASA type rating and license endorsement list, flight crew – all aircraft excluding helicopters", 12 February 2018.
- The Israeli CAA (CAAI) has adopted the rules and decisions of the EU in this matter.

1.7.3 Inexperienced pilot per OM A

- A first officer is considered inexperienced prior to accumulating 100 flight hours as a FO at the controls of the model a/c, as per Chapter 13 of the Israeli Air Regulations.
- A captain is considered inexperienced prior to accumulating 100 flight hours as a pilot in command of the model a/c, as per Chapter 13 of the Israeli Air Regulations.
- There is no such “inexperienced” period for a crewmember converted from the 777 to the 787 fleet.

1.7.4 Crew assignment for flight per El Al procedures (CAAI-approved)

OMA paragraph 4.1.2 for a double crew:

<table>
<tr><td rowspan="2">Double Crew</td><td rowspan="2">PIC — CAPT
Co-pilot 1 — CAPT
Co-pilot 2 — F/O or CAPT
Co-pilot 3 — F/O or CAPT
NOTE: If all three Co-pilots are Captains, at least one of them shall have RHS qualification.</td><td rowspan="2">If the PIC is Inexperienced, at least one F/O or CAPT-RHS shall be Experienced.</td><td>Cruise/ En-route (See Note 2)</td><td>CAPT</td><td>Any Co-pilot</td></tr>
<tr><td>Other Phases</td><td>PIC (See Note 3)</td><td>F/O or CAPT-RHS</td></tr>
</table>

<u>Note</u>: The above implies that a captain who just recently transferred from the B777 fleet and has only performed one B787 flight under the supervision of a check airman, can be assigned to a flight with a completely “inexperienced” crew. Actually, a captain converted from B777 can act as checker at the B787 fleet without going through the “inexperience period” on this a/c, while in a conversion to another model he should go through the usual “inexperience period” and accumulate additional experience on the a/c before becoming a checker.

OMA paragraph 4.1.4 regarding “experience accumulation” flights, such as training flights and post-conversion examinations, with the FO in training:

<table>
<tr><th>IOE / SOE</th><th>Phase of Flight</th><th>Left Seat</th><th>Observer Seat</th><th>Right Seat</th><th>Composition</th></tr>
<tr><td rowspan="2">First Officer IOE</td><td>Critical Phases</td><td>Check Airman (PIC)</td><td>-</td><td>First Officer IOE</td><td rowspan="2">• Check Airman (PIC)
• Captain
• First Officer IOE
• First Officer</td></tr>
<tr><td>Non Critical Phases</td><td>Check Airman (PIC)</td><td>-</td><td>First Officer IOE</td></tr>
</table>

Note: There is no reference to the experience of the other crew members, it is sufficient for the captain to be a checker and to ocupy his seat when the FO ocupies his.

1.7.5 Night curfew at Ben Gurion airport

Per AIP Israel, Airports, Ben Gurion, Noise Abatement chapter – Night flights limitations:

- Runway 30 is not available for takeoffs between 23:00-06:00 local time, unless approved by the airport manager due to unusal circumstances.
- Other runways are not available for takeoffs between 01:40-05:30 local time in the winter and 01:40-05:00 in the summer (seasons per ICAO definitions).
- Takeoffs between 01:40-02:00 will be approved by the airport manager in special cases only.

1.7.6 Service passengers and holiday flights in El Al procedures

Being an airline, El Al's flight crews are frequently staying at overseas stations. El Al employees and their family members, as in other airlines in the world, are eligible for discounted flight tickets, on a seats available basis. An employee or family member using any type of discounted ticket is reffered to as "service passenger".

Company procedure 42-017 "Service passengers – boarding" deals with boarding service passengers on El Al flights.

Company procedure 11-06-01 "Priorities for flying on duty and on vacation" deals with the priorities for boarding, including upgardes to business class.

El Al has recognized Rosh Hashana (Jewish New Year) and Passover eve ("Seider") as special dates, in which special attention should be given for the stay of an employee/crew member out of homebase. A crew member assigned to flights requiring overlay at these times is eligible to receive flight tickets for his family members on a seat available basis.

The above company procedure provides "preferred priority" to service passengers who are family members accompanying an active crewmember on a holiday flight.

1.7.7 Aviation flight and rest time limitations

The Israeli 1971 Air Regulations ("Flight time limitations in aviation services") set the limitations for the required duty, flight and rest times.

El Al has a collective labor agreement. Chapter 25 in the agreement, "Flight crew work arrangements" sets the limitations for assigning flight crews and for their rest times. In general, they are more restrictive than the Air Regulations. A crew member may waive his rights per the labor agreement but should never exceed the limitations of the Air Regulations.

Excerpts from the regulation – Definitions:

"Duty Time", for a crew member – The amount of time, during which he is required by the operator to be at a certain location, excluding a resting place or flight time, as a member of minimum crew, member of double crew, member of augmented crew or a passenger on the aircraft (below, in this definition – work), and if between one said work period and a second work period there was a recess not exceeding 8 hours, such recess will be calculated as said work time; But if the crew member is not employed at international air lines and his employer has provided him with a resting place, the time of such recess will not be considered as work time;

"Flight Time", for a crew member – The amount of time during which he is on duty at the cockpit, from the moment the aircraft first moved on its own power towards takeoff until the moment it shut down its engines at the end of the flight;

"Calendar Day" – Continuous 24 hours;

"Rest before duty", for a crew member - Rest before duty time at a resting place provided to him by the operator;

"Double Crew" – A crew consisting of a sufficient number of crew members which will enable simultaneously replacing all members of the minimum crew

"Augmented Crew" – A crew consisting of a sufficient number of crew members which will enable role replacement among crew members and alternating rest

"Minimum Crew" – A crew consisting of the smallest number of persons required to operate an aircraft as determined in the manufacturer's aircraft manual and in the operating procedures which were determined according to the license;

Excerpts from the regulation, paragraph 2 – Flight time limitations:

An operator will not employ a crew member and a crew member will not act continuously, for a flight time exceeding the times detailed below:

(1) In a commercial flight -

(a) In a calendar day

1. In an aircraft operated by a single pilot or a single pilot and an additional crew member – 8 hours.
2. In an aircraft whose minimum crew includes at least 2 pilots and one other crew member – 12 hours;

Excerpts from the regulation, paragraph 3 – Duty time limitations:

An operator will not employ a crew member and a crew member will not act continuously, for a duty time exceeding the time detailed below:

(1) In a commercial flight –

(a) If the crew member was at that time part of a minimum crew which includes a single pilot or a single pilot and an additional cew member – 14 hours; If the said crew is an augmented crew – 17 hours and if it is a double crew – 19 hours;

Excerpts from the regulation, paragraph 4 – Minimum rest time:

An operator will not employ a crew member and a crew member will not act in a commercial flight, shortly after the end of a duty time period in the context of duty time limitations according to regulation 3, unless he had sufficient time to rest at a resting place, rest before duty, which should not be shorter than the following:

Number of duty hours hours prior to additional duty	Number of duty
Up to 10	8
More than 10 but less than 11	9
More than 11 but less than 12	10
More than 12 but less than 13	11
More than 13 but less than 14	12
More than 14 but less than 15	13
More than 15 but less than 16	14
More than 16	14 plus 1 more hour for every hour on duty beyond 16 hours.

Duty Period definition in El Al procedures:

Per OMA definition chapter – For an active crew, the whole flight time from 75 minutes before scheduled departure time and until 15 minutes after chocks time.

Note: This time of course includes the ground turnaround time at an overseas station.

Note: The above rules are no longer in effect as new FTL rules, as per F.A.R 117 were implemented and a new labour contract signed.

1.8 Additional information

1.8.1 Safety events & accidents due to errors in takeoff performance calculations

Several accidents have occurred in the world as a result of using too low weight for takeoff calculations.

The oustanding accidents:

- 24-8-1999 – B767-300 a/c took off from Copenhagen and struck its tail during the rotation. The investigation found that the crew has entered the ZFW value at the TOW line and used it for takeoff calculations.
- 14-10-2004 – B742 cargo a/c attempted a takeoff from Halifax and crashed right after lift off. The investigation found that the crew takeoff calculations were based on the previous flight's gross weight, which was substantially lower that the actual weight.
- 20-3-2009 – A-340 a/c took off from Melbourne. The a/c hardly lifted off the runway, struck its tail and hit the approach lights system of the opposite runway.

In view of the accumulation of similar events, 2 researches were conducted, which tried to determine the root causes and to outline ways to mitigate the risk.

- "Use of Erroneous Parameters at Takeoff" – Conducted in France, published in 2008. Analyzed 10 investigation reports of events of this type.
- "Take-off performance calculation: A global perspective" - Conducted in Australia, published in 2011. Analyzed 32 investigation reports of events of this type, in Australia and worldwide.

The main findings and conclusions of the Australian research :

- Typical mistakes :
  - Use of ZFW instead of TOW.
  - Weight error – mistake in entering a digit.
  - Erroneous copying of takeoff speeds to the a/c systems.
  - Using previous flight's data.
  - Not revising parameters following change of runway or deteriorated conditions.
  - Copying a wrong parameter from weight & balance form or takeoff card.
  - Using wrong data pages.
  - Using a wrong table or a wrong column in a table.
  - Erroneous conversion of units (weight or volume).

- Typical results :
  - Tail strike.
  - Degraded takeoff performance noticed by the crew.
  - Degraded a/c performance after takeoff, climb performance or narrow maneuver margin.
  - Rejected takeoff due to slow acceleration.
  - Runway overrun, either in aborted takeoff or the a/c could not lift off.
  - Pushing TOGA during takeoff roll to obtain full takeoff power.
  - Using a runway length longer than planned – Rotation at slow speed resulting in a nose high attitude for lift off, increased drag.
  - Takeoff at a weight higher than the limit.
  - Less than required obstacle clearance after takeoff.

- The research identified 131 Contributing Factors for the reviewed accidents and incidents. They were divided into 4 categories:
  - Individual actions - 39%
  - Organizational influence – 2%.
  - Risk control – 31%.
  - Local conditions – 28%.

- The research conclusions (Items relevant to the case of this investigation are emphasized) :
  - Despite technological advancement and detailed procedures, accidents and incidents are still occurring during takeoff, which is considered the flight's most critical phase. 12% of the global commercial aviation fatal accidents between 2000 and 2009 occurred on takeoffs, although the takeoff amounts to less than 1% of the overall flight time.
  - The research dealt with accidents, which happened when crews using erroneous takeoff data attempted to lift off the runway at a speed and power lower than required. However, the error was detected before takeoff in numerous similar cases.
  - There are various reasons for the errors, including speeds, weights and mistaken runway data. Crew errors included using incorrect parameter, incorrect entering of a correct parameter, obsolete data, ignoring certain parameters, and more. Systems involved included, among other things tables, applications, computers, FMC ,ACARS ,MCP, takeoff cards and more.
  - Primary elements of crewmember errors were cross checks & monitoring, planning & evaluation, equipment operation.
  - External influences included insufficient experience, time pressure, distractions, insufficient mission information.
  - At the risk control level the research identified inadequate procedures, a/c systems with lower-than-optimum design, inadequate crew management and inadequate training.
  - The research states that the issue cannot be resolved by a single method and offers a series of items for examination, including : Improved operating procedures, mainly in the area of cross checking; proper crew assignment considering the crew experience on the a/c type; crews should perform adequately even under circumstances of distraction and time pressure.

- The conclusions of the research indicate that such incidents and accidents can occur to any airline, any aircraft model and any pilot – no one is immune. Since human beings are prone to making mistakes, the aviation industry should continue to look for means to reduce the opportunities for error and to maximize the crews' capabilities to discover an error before it leads to severe outcome.

1.8.2 Takeoff Performance Monitoring System

- Flight safety has been improving significantly over the years in almost all parameters. One area where improvement was minor is the takeoff roll. NTSB data indicate that about 9% of commercial aviation accidents in the 90s have occurred during takeoff or aborted takeoff.
- Such data have led to identifying the need for installing systems, which will monitor takeoff parameters and will provide the crew with a reliable indication about its execution and a supporting tool for the decision whether to continue or abort a takeoff.
- With such systems installed, the number of accidents in this critical flight phase could have reduced and their severity could have decreased.
- NASA has developed the TOPMS and in 1994 conducted a test on a B737-100 passenger airplane. A computerized monitoring system, which displayed the a/c position on the runway, its acceleration, state of the engines and several other parameters, was installed on the a/c.
- The test was successful and demonstrated that using such a system is feasible. Yet it was determined additional work is required in order to determine the allowable margins and to prevent unnecessary takeoff aborts. It was further determined that a tool to support the stop/go decision is an important component of the system and has to be developed. Another recommendation was to improve the measurement of ground speed and its integration with the system.
- In the wake of the B747 crash in Halifax on 14-10-2004, the Canadian investigative authority has recommended to Transport Canada Civil Aviation (TCCA), as well as to FAA, EASA, ICAO and other safety organizations to generate a requirement for Transport Category a/c, to be equipped with a runway performance monitoring system, capable of providing the crew with reliable information about insufficient takeoff performance.

- TCCA concurred that such a system could improve safety but rejected the recommendation, saying that a sufficiently reliable system is not available and hence cannot become a requirement. TCCA contended that an active yet insufficiently reliable system would increase the risk of unnecessary takeoff aborts at high speeds. If such a high reliability system will become available in the future, the authority will reconsider its position.
- For a case with features like this investigated event, such a system would not have been helpful. The system can define an acceptable range of data for a given weight and for external conditions, but if the system is fed with a wrong parameter, the system's calculations will also be in error. Nevertheless, it is possible that TOPMS could have initiated an alert due to low acceleration.
- As of now, Boeing aircraft do not have takeoff performance monitoring systems installed.

1.8.3 El Al takeoff performance errors, safety events

The investigating team has checked the number of safety events related to takeoff performance calculation at El Al over the last 10 years. Findings:

- Between 2008 & 2018 there were 10 reported events at El Al, of which 2 were classified as "negligible", 7 as "low" and 1 as "moderate".
- Some of the errors were detected before takeoff and some in retrospect.
- Error characteristics included : Using wrong runway or airport data, wrong flaps position (mostly due to re-calculation following change of conditions), lack of V-speeds display, deteriorating conditions not accounted for by the crew, weight error and error in entering temperature for power calculation with ATM method.
- Additionally, in a number of cases, correct performance calculation was followed by erroneous thrust application – 2 cases of B767 a/c taking off with CLB thrust and one B777 a/c using TO-2 instead of TO.

1.8.4 World aviation accidents risk factors

Aviation world commonly divides human errors into 12 key risk factors, called the "Dirty Dozen". This classification method was first introduced in 1993 by Gordon Dupont for the area of aviation maintenance but was subsequently accepted as a list of risk factors for other areas, including pilots' human errors. The list:

- Lack of communication
- Distractions
- Lack of resources
- Pressure, tension
- Complacency
- Inadequate team work
- Time constraints
- Inattention
- Lack of knowledge
- Fatigue
- Lack of assertiveness
- Faulty work norms.

It will be shown and analyzed later that 8 of the above 12 factors have played a role, definitely or with a certain probability, in the scenario which caused the error in data entering & calculation as well as the fact that it was not detected in time.

1.8.5 Swiss cheese model

- James Reasons of Manchester University first introduced a model accepted by ICAO for investigating the role of the human factor in aviation accidents & incidents in 1990. The model describes the causes for an accident as several layers of failures, some of which are latent failures, some are active and some are active & latent. A plate with holes in it represents each layer.
- For an accident to get the opportunity to happen, all failures, or holes, should align with each other. This model was named the "Swiss Cheese Model".
- An active failure is a direct action of a crewmember, which caused a severe outcome. For instance – Retracting the flaps instead of the landing gear, thus causing the a/c to stall after takeoff.
- A latent failure is a factor in the background, such as a tight schedule causing time constraints, inadequate operating procedures, inadequate crew assignment, etc. These factors exist in the background all the time, but at a particular opportunity, they align with a crewmember's active failure and materialize to a severe incident or accident.
- Accident is never a result of a single factor.
- The Swiss cheese model is accepted for human factor investigations and is included in ICAO's "Human Factors Digest".

1.8.6 Safety barriers theory

- The Safety Barriers theory contends that blocking any of the above failures will prevent the accident.
- Safety barriers are classified and have a common hhierarchical arrangement as follows:

  First Barrier – Regulation

  The regulator sets laws and limitations, which are aiming to assure adequate safety level, prevent hazardous situations and reduce the probability of their occurrence.

  Second Barrier – Technology

  Modern a/c design and manufacture include accumulated knowhow and experience, including ramifications from incidents & accidents. Aircraft systems are designed to actively protect against exceeding the flight envelope and to warn the pilots when approaching the limits.

  Third Barrier – Procedures

  This barrier consists of four layers (PX4):

  Philosophy – The overall concept of an operator of how its airplanes should be operated.

  Policy – The way the manufacturer and the operator define the way the company's airplane should be operated.

  Procedures – Specific operation procedures defined in the airplane manuals and the company's operating procedures.

  Practices – Processes developing among the pilots in order to complete tasks, which are not mentioned in the written procedures and to support remembering sequences of tasks. For instance, couplings such as the action of extending the landing gear, with the cabin chime and the landing lights switching on. Personal developing of work habits which help crewmembers not to forget tasks.

  Fourth Barrier – Personal dimension

  The crewmember's awareness of his own medical and mental condition, his alertness and his situational awareness.

  Fifth Barrier – Crew Resource Management (CRM)

  The ability to manage crew resources in order to execute all required flight procedures, conduct effective cross monitoring, maintain adequate situational awareness and make appropriate decisions.

1.9. The investigation

1.9.1 The investigation was conducted with cooperation of El Al and included:

- Interviews with the crew members
- Conversation with B787 fleet manager
- Checking the flight's schedule & background
- Review of El Al's B787 a/c manuals
- Review of El Al's Operations Manual (OM A)
- Review of El Al procedures
- Review of Israeli Air Law and Air Regulations
- Analysis of data from FOQA/EAFR
- Analysis of the subject flight versus a normal flight
- Analysis of the risks in this takeoff
- Analysis of the human factor
- Continuous consultation with Boeing safety experts
- Review of research regarding similar cases in world aviation.

1.9.2 The subject event was classified as a severe incident, in accordance with the condition defined in paragraph 103 of the Israeli Air Law:

A "Severe incident" – An aviation incident under circumstances in which an accident almost occurred.

1.9.3 Investigation method

- Initial examination of the flight's information yielded a concrete concern that a severe tail strike on takeoff was a probable scenario.
- Takeoff parameters raised a concern for impacted maneuver margins and risk of loss of control after liftoff and during flaps retraction.
- The investigating team checked the parameters of the takeoff, namely the actual weight and the data calculated with a wrong weight. It confirmed the concerns that tail strike risk on liftoff was a probable scenario, which was prevented most probably by the tail strike protection built into the aircraft flight control system.
- The takeoff was compared to a normal takeoff, using correct data and weight.
- The concern for loss of control did not materialize, for reasons explained in the analysis.
- The investigating team analyzed the takeoff under scenarios of continued or aborted takeoff following potential loss of the critical engine at the decision speed.

- The incident stemmed from a human error and from the flight crew's behavior, which did not detect and correct the error. The investigating team has studied the a/c systems and compared the standard process of a normal flight with the process, which occurred on this flight.
- The investigation found several vulnerabilities, which at a certain probability have caused an entry error and subsequently a computation error, both of which were not detected. Such vulnerabilities might cause other incidents under different circumstances.
- The investigating team cross checked data from various sources, including the a/c manuals, Israeli and European regulations, data acquisition systems, comparison of the takeoff with a normal takeoff, company procedures, etc.
- The team reviewed research by world leading safety organizations regarding similar events and regarding the human factor in accidents and flight incident in general.
- The human factor in this incident was analyzed with acceptable models:
  - "Swiss Cheese" model
  - Failure Safety barriers
  - Threat and Error Management (TEM).
- Conclusions and recommendations were established which, in the opinion of the Chief Investigator can counter some of the vulnerabilities discovered and reduce the potential for similar events in the future.

2. Analysis

Analysis of the event will focus on two main aspects:

- The effect of the error on the aircraft performance and the resulting risks, under the takeoff scenarios of two engines (AE) and a critical engine failure (EO).
  - Comparison of the incident calculations to the correct weight values.
  - Aircraft sensitivity to tail strike.
  - Aircraft sensitivity to stall after liftoff.
  - Aircraft sensitivity to airspeeds and maneuver margins during initial climb and flaps retraction.
  - Aircraft sensitivity to maneuver margin during climb to cruise altitude.

- The human factor:
  - Analysis of the incident according to the Swiss Cheese Model.
    - ✓ Active failure – What has directly caused the error on this flight?
    - ✓ Latent failures, which could contribute to the materialization of the error and to the fact that it was not detected.

      Note: Inherently for latent failures, it is impossible to prove which one has actually contributed to the occurrence of the incident, and they often have an accumulated effect.
  - Analysis according to the CRM Threats and Errors Model (TEM).
  - Analysis according to the Failure Barriers Theory, which barriers did function and which ones did not.
  - Crewmembers' fitness for continuation of flight following a serious safety event.

2.1 Effect of the error on aircraft performance

- General: The crew computed takeoff parameters based on a low weight. Consequently, the calculated thrust and speeds used for takeoff were substantially lower than required for the actual gross weight. On the other hand, the thrust setting and takeoff speeds were adequate for the gross weight used.
- Calculating too low thrust and speeds have a hazardous effect in several areas:
  - ✓ Acceleration substantially lower than required.
  - ✓ Reaching V1 decision speed at a runway point different than required.

    Note: This issue is somewhat compensated for by the low calculated V1.
  - ✓ Rotation at speed and thrust lower than required implies lower than reqeuired lift for lift off and initai climb. They also result in higher pitch attitude for lift off – Risk of tail strike.

- ✓ Raising the nose at low speed and low thrust to a higher than normal pitch attitude - Impacts the aicraft acceleration capability.
- ✓ Lift off at lower than required speed and thrust - Impacts the necessary manuever margins, with risk of stall and loss of control.
- ✓ Low speed and low power after lift off imply degraded climb performance.
- ✓ For a scenario of engine failre at V1 and aborted takeoff, specific calculations should be made, because the variation of the point of decision speed along the runway might be offset by the lower calculated speed.
- ✓ For a scenario of engine failure at V1 and continued takeoff, all of the above effects on rotation and climb performance, including required climb gradient and obstacle clearance, are aggrevated, potentially up to a situation in which the aircraft will not be able to lift off the runway.

2.1.1 Computed power and takeoff speeds – Correct data versus the crew calculations

<u>Correct computation according to true data</u>

Computed parameters on which the takeoff was made

Comparison Table

	FLAPS	SEL TEMP	TPR	V1****	VR	V2	Vref
TRUE	5	40	75	167	172	176	170
FALSE**	5	55	67***	152	154	158	154
MARGIN	**0**	**15**	**8**	**15**	**18**	**18**	**16**
NO IMPR.*	5	38	80	165	169	173	170
MARGIN*	5	17	13	13	15	15	16

Table notes:

(*) This line presents a correct calculation, without “IMPROVED CLIMB”, in order to properly compare the takeoff sensitivity.

(**) Takeoff data per the wrong weight, without IMPROVED CLIMB, were checked and found identical to data with IMPROVED CLIMB, i.e. the “IMPROVED CLIMB” would not have contributed to takeoff performance at the wrong weight.

(***) 67% TPR is the maximum thrust reduction at ambient temperature of up to 29 Deg. And local pressure altitude when using ATM method alone (In a combined method an additional reduction could be obtained).

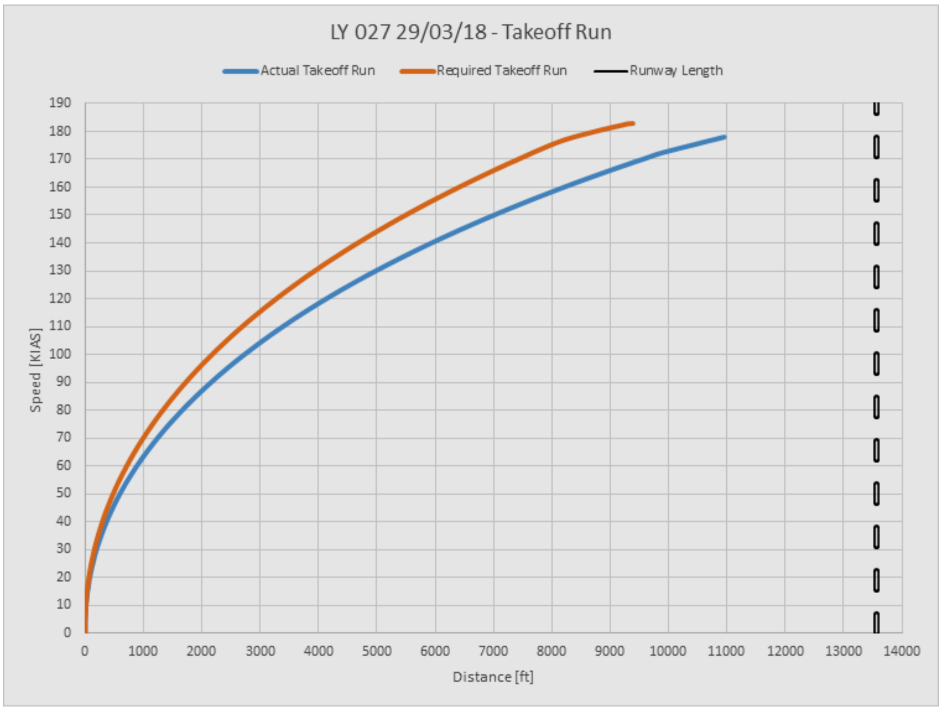
(****) In both cases the V1 speed was determined by the obstacle clearance limitation.

2.1.2 Takeoff speeds perfromance along the runway

Theoretical takeoff performance for the true gross weight and required thrust

Takeoff speed along the runway

Comparison of the actual case to true weight requirement



Comparison of takeoff run distances (Feet)

	V1	Vr
REQUIRED	7,000	7,400
ACTUAL	7,100	7,400

Note: "REQUIRED" => Without "IMPROVED CLIMB"

Conclusions from the chart and table:

- The aircraft reached the runway point of erroneous V1 at a distance of 7,100 feet, instead of 7,000 feet if the takeoff would have been made at correct thrust and speeds. For a scenario of aborted takeoff at V1 (Accelerate-Stop), the point of initating pilot actions would be 100 feet further down the runway, but the speed upon brakes application would be substantially slower. Thereofre the aircraft would have been able to stop on the runway, either with two engines operating or single engine.
- For a scenario of continued takeoff from V1 (Accelerate-Go), the aircraft would have reached the Vr point at about the same distance, because it only had to accelerate by 2 more knots (152-154 knots).

  Note: The chart presents a two engines scenarion, does not account for single engine.
- From the point of perceiving distances along the runway, the crew was unable to detect the error.
- Acceleration was substantially slower than normal – 41 seconds from 30 knots to 154 knots, compared to 43 knots from 30 to 180 knots, measured on a flight under similar conditions. None of the crewmembers noticed the slow acceleration.

2.1.3 Rotation process

- Take off data from the EAFR, in seconds since brake release:
  - ✓ 41 Sec. – Reaching Vr, 154 knots.
  - ✓ 42 Sec. – Beginning of pulling the column.
  - ✓ 44 Sec. – Column reaches max aft travel. Elevators average angle 10.3 Deg., speed 163 knots, nose starts coming up.
  - ✓ 45 Sec. – Aircraft is airborne, sped 166 knots. Elevators average angle 9.7 Deg.
  - ✓ 46 Sec. – Speed 167 knots. Pitch attitude increasing. Aircraft is not climbing.
  - ✓ 47 Sec. – Speed 168 knots. Pitch attitude increasing. Aircraft is not climbing.
  - ✓ 48 Sec. – Speed 170 knots. Aircraft starts climbing. Pitch attitude 9.0 Deg., elevators average angle 9.1 Deg. Minimum measured tail clearance 29.3”.
  - ✓ 49 Sec. – Speed 171 knots. Tail clearance increasing to 30”, pitch attitude 9.2 Deg., aircraft climbing.
  - ✓ 50 Sec. – Climb speed 172 knots. Tail clearance continues to increase, pitch attitude 10.4 Deg., elevators average angle 12.4 Deg.
  - ✓ 53 Sec. – Airspeed 175 knots. Altitude 35 feet above the runway.

- ✓ Climb continued to 1,500 feet, airspeed 174 to 180 knots.
- ✓ Climb from 1,500 feet to acceleration altitude at airspeed between 180 to 186 knots.

➢ Data analysis in comparison to a normal takeoff, using FCTM data:

- ✓ On this takeoff the PF began pulling the column aft 1 second after reaching rotation speed, a reasonable time period.
- ✓ On a normal takeoff, the aircraft is supposed to reach the lift off pitch attitude of 6-7.5 Deg. and lift off within 3 seconds after rotation speed. On this takeoff, the aircraft transmitted "airborne" after 4 seconds, but began gaining altitude only 6 seconds since the beginning of pulling the column.
- ✓ Pitch attitude at lift off was 9.0 Deg., while the normal lift off pitch attitude is 6-7.5 Deg., and the theoretical angle for tail strike is 9.7 Deg.
- ✓ On a normal takeoff, the aircraft should reach 35 feet at V2+15 within 6-7 seconds. On this takeoff, it only began gaining altitude after 6 seconds and reached 35 feet after 13 seconds!
- ✓ Elevators angle at the rotation phase on a normal takeoff is fairly consistent. On this takeoff, the elevators angle began at 10.3 and then, for the same aft angle of the column, when tail clearance was minimal, the elevators angle decreased to 9.1 Deg. and then increased continuously.

➢ Conclusions from the data analysis:

- ✓ Rotation was very slow because its initiation at low speed and the low engines' thrust did not generate enough lift to raise the nose and lift off the runway, until the aircraft gained 12 knots above rotation speed and 10 knots above V2.
- ✓ Elevators angle changes while the control column angle was mostly constant indicate that the flight control system feature protecting against tail strike by reducing elevators angle has operated and practically prevented an accident.
- ✓ The smallest tail clearance was 29.3" and did not exceed the 29" minimum clearance specified in the FCTM. The reason for maintaining the clearance was that the lift off speed was substantially higher than the miscalculated rotation speed, and the elevator system features precluded further reduction of the tail clearance.

2.1.4 Vmu speed versus Vlof speed

Vmu is defined as the minimum speed, at which the aircraft can lift off "without hazardous characteristics". Some aircraft types are limited by stall speed and other types are limited by the pitch attitude at lift off. The B787's Vmu is limited by pitch attitude, i.e. – the minimum speed, at which the aircraft can lift off the runway without a tail strike.

For aircraft types limited by pitch attitude, including the B787-9 the ratio Vlof/Vmu is 1.04 in the single engine (EO) scenario and 1.08 in the two engines (AE) scenario.

For a correct calculation of Vlof, the "IMPROVED CLIMB" option should not be considered.

Calculation of takeoff data for the actual gross weight, without "IMPROVED CLIMB" resulted in Vr=169 knots and V2=173 knots. Using a conservative assumption that Vlof=Vr yields Vlof of 169 knots.

The resulting Vmu for AE is 157 knots.

The resulting Vmu for EO is 162 knots.

The speeds calculated for the wrong weight were Vr=154 knots, V2=158 knots.

Conclusions from this calculation:

- Rotation was initiated at a speed lower than Vmu for the actual weight.
- The flight control system feature for protecting against tail strike has operated and did prevent tail strike on the takeoff.
- In an engine failure at V1scenario, with engines' thrust substantially lower that required, an attempt to raise the nose at a Vr which is 8 knots lower than Vmu would result in insufficient lift for becoming airborne and would cause a nose high attitude, generating increased drag and degrading acceleration. It is highly probable that under these conditions the aircraft was not able to lift off without a substantial thrust increase.

2.1.5 Stall speed Vs

One of the risks examined was an aircraft stall immediately after liftoff. This scenario has low probability, because a stalling aircraft cannot generate lift for liftoff and climb, except for using the ground effect.

Vs calculation: $V_S = \sqrt{\frac{2W}{\rho S_W C_{L_{Max}}}}$

Where:

- W – Aircraft weight
- ρ - Air density
- S_w - Wing area
- $C_{L_{Max}}$ - Maximum lift coefficient.

Ground effect is operating at a low height, about ½ of the aircraft wingspan (About 100 feet for the B787-9). It is difficult to calculate ground effect because it is not linear. Using a conservative assumption that ground effect increases the lift coefficient by 25% provides the following computation:

$$V_s = \sqrt{\frac{2 \cdot 235000 \cdot 9.81}{1.225 \cdot 377 \cdot (1.21 \cdot 1.25)}} = 81 \left[\frac{m}{sec}\right]$$

Conversion to knots provided Vs=157 knots.

The calculated speeds at the incident were Vr=154 knots, V2=158 knots. Hence, using the conservative assumption that ground effect adds 25% to the lift coefficient, results in a Vr lower than Vs and in V2 1 knot higher than Vs.

Conclusions for the Vs computation:

- Vr calculated by the crew was lower than Vs computed with ground effect.
- V2 calculated by the crew was about the same as Vs.
- The Vr & Vs values explain why, after rotation was initiated and the column was pulled at 155 knots the aircraft remained on the ground and only at 166 knots became airborne.
- Being near the stall speed explains why pulling the column and elevators movement did not generate altitude gain, until 6 seconds after the pull was initiated, upon reaching 168 knots, 14 knots higher than rotation speed.
- Continued climb to 3,000 feet was initially performed at speeds of 173-180 knots, which are at or above V2 for the actual weight. Subsequent climb speed exceeded 180 knots. Therefore, throughout the climb above 50 feet height the airspeeds flown provided sufficient maneuver margin.

2.1.6 Initial climb

Initial rate of climb was meagre. The aircraft reached 35 feet 13 seconds after rotation was initiated.

Under an EO scenario (without thrust increase on the operating engine), the aircraft would have a difficulty gaining airspeed and climbing. If the takeoff was limited by obstacle clearance, the rate of climb would have provided a questionable clearance and certainly could not provide the 2.4% gradient required by regulation.

2.1.7 Climb thrust

At 1,500 feet AGL the engines went into full climb thrust - CLB, with TPR=62.5%. This value is varying with airspeed and atmospheric conditions but does not vary with weight and hence the calculation error did not affect the performance.

2.1.8 Maneuver margin during flaps retraction

The flaps retraction process is sensitive to maneuver margin. It is desirable to clean up the configuration as soon as feasible, since high airspeed and a "clean" aircraft provide better climb performance and fuel savings. On the other hand, flaps retraction at a speed lower than required can affect the aircraft maneuver margin and get it closer to stalling. This margin is expressed in terms of "g" or bank angle in a level turn.

Maneuvering speeds for the weights relevant to the incident (According to FCOM-PI):

Weight	Vzf	F1	F5	Vref
238 tons	258	236	208	170
198 tons	237	216	194	154
Difference	21	20	14	16

Note: According to the QRH, the differences between flap settings UP/1/5 are exactly 20 knots - Vref+80/60/40 knots, respectively.

Maneuver speeds for the flap settings provide for at least "Full maneuver capability", equal to 1.3 "g" or 40 degrees of bank in level turn (25+15=40 Deg.).

The lowest maneuver margin is obtained while retracting flaps from 1 to UP. Retraction at flaps 1 maneuver speed reduces the maneuver margin momentarily to 1.24 "g".

The “bugs” displayed on the airspeed indicator are computed by the FMC based on aircraft weight. Once a wrong weight was entered the bugs’ locations were also wrong, at speeds lower than required for the actual weight.

The difference between the flaps 1-maneuver speeds for the wrong and the correct weight is 20 knots.

Flaps retraction while accelerating through the maneuver speed is supposed to provide a temporary margin of 1.24 “g”, but if conducted 20 knots earlier the margin is substantially reduced.

Since the process is typically performed while climbing, accelerating and with wings level and low load factor, and sometimes retraction is initiated above the maneuver speed for the flaps setting, the real margin is actually higher than above and is displayed on the airspeed indicator as the AMBER BAND.

Checking of FOQA data did not indicate a significant increase in angle of attack during flaps retraction (Not compared to flaps retraction on another takeoff).

Note: The actual flaps settings and retraction schedule could not be obtained due to a malfunction in the aircraft data acquisition system.

2.1.9 Cruise performance

- The crew detected the weight error while checking the cruise performance in the FMC – Optimum, recommended and maximum cruise altitudes.
- The crew corrected the error.
- The “Long Range Cruise Maximum Operating Altitude” table indicated a max cruise altitude, limited by engines’ thrust, of about 37,000 feet, for the conditions of ISA+10C AND BELOW and a weight of 235 tons (Estimated weight at the beginning of cruise). The optimum cruising level presented to the crew, based on the erroneous weight was about 38,000 feet.
- Therefore, under the above circumstances the aircraft could not climb to the calculated optimal altitude. No doubt that the crew would have noticed it eventually.

2.1.10 Summary

Analyzing the actual takeoff and climb data, compared to data which corresponds to the actual gross weight indicate:

- The aircraft accelerated slowly and reaching the wrong Vr of 154 knots took the same time that on a normal takeoff would take to reach about 175 knots.
- The point along the runway, where the aircraft reached V1 was slightly further than the correct point for the actual weight, but not to an extent that could be noticed by the crew.
- The location of the decision point along the runway would enable aborting the takeoff safely, either in AE or in EO scenario, because the aircraft reached the decision point at a speed substantially slower than required.
- The location of the decision speed along the runway, combined with the low Vr and V1, raise a doubt whether the aircraft could lift off in case of engine failure, unless the crew would have increased thrust on the operating engine.
- Since rotation was initiated at a speed close to the stall speed the aircraft initially did not raise the nose and did not lift off until gaining 13-14 knots above Vr.
- After liftoff the aircraft had a low rate of climb and accelerated due to the ground effect, reaching height of 35 feet in 13 seconds after rotation, which is twice the normal time.
- The tail-strike protection feature of the flight control system has reduced elevators angle until sufficient airspeed has been achieved. Therefore the smallest tail clearance did not get below the 29“, minimum specified in the manuals and a tail strike did not occur.
- Aircraft maneuver margin during climb did not decrease below the safe margin, because climb speeds were higher than V2 calculated for the actual gross weight.
- Maneuver margin during flaps retraction could have been substantially affected during retraction form flaps UP to 1, but in reality there was no hazardous proximity to a stall, apparently due to low load factor associated with acceleration in climb with level wings.
- At its actual gross weight the aircraft could not climb to the optimal cruise altitude calculated by the FMC based on the wrong weight.

2.2 The human factor

2.2.1 Active and Latent failures in this case

- **Active failure – Direct cause for the incident – Entering a wrong ZFW in the PERF INIT page**

The crew arrived at the aircraft when the flight was already "closed" from the aspect of weight and balance. Cap1 reviewed the load sheet with FO1 and concurrently entered the ZFW into the flight management system. He entered one wrong digit. He immediately detected his error, stated that he made a mistake but in correcting it he re-entered the same wrong parameter.

The investigating team considered various possible ways for data entering errors and concluded the probable scenario is the captain's re-entering a wrong parameter.

The other possibilities were:

- Not marking the ZFW line on the CDU and entering the parameter in another line. This possibility was rejected, because the other line, which could be entered, on the left side of the PERF INIT screen, is RESERVES. Had this line been entered with a value of 168 tons, the system would have generated an error message or "Insufficient fuel" message.
- Entering the parameter on the right side of the screen would have caused an error message due to wrong data format and incompatibility with the data to be entered in these lines.
- Another possibility was writing the ZFW value on the Scratch Pad without actual entering it to the page. This possibility was rejected, because the figures would have remained on the scratch Pad and would later be observed while entering additional parameters.
- The possibility that EXECUTE was not entered was also rejected because weight data does not require this command.

Cap1 and FO1 did not detect the error and continued acting according the wrong ZFW and the resulting wrong gross weight.

- **Active failure – Main contributing factor to the incident – Ineffective crosschecking by the PF over the entering of data by the PM**

  FO1 did not follow the process of entering the weight data into the FMC by CAP1 and was not aware of the error and of the attempt to correct it.

  It was the FO1'a duty as the PF to crosscheck all values entered by CAP1 into the FMC. It is highly probable that FO1 did not check the PERF INIT page and did not detect the error entered to the ZFW line and the wrong gross weight. It is highly probable that neither crewmember has reviewed the VNAV CRZ page. Reviewing this page would have most probably exposed the error while still on the ground, as has eventually happened during climb.

  Note: Reviewing the cruise page is not required in the departure process but many crewmembers are regularly reviewing it.

- **Active and latent failure later in the process – Performance calculation**

  As described before, the FO conducted the initial preparation of the OPT screen and entered the ZFW value from the dispatch documents.

  The active crewmembers proceeded to do the calculations based on gross weight from the FMC. It should be noted that using a value from the screen is common, since El Al's procedure dictate using ramp weight value for takeoff calculation. The GR WT parameter represents the ramp weight, based on the ZFW entered by the crew with the addition of the fuel quantity derived from the sensors in the fuel tanks. After being checked, the form is typically located at the captain's side, while the FMC weight data are visible to both crewmembers.

  Cap1 mistakenly entered a 16 Deg. DP (dew point) in the temperature line. FO1 commented about it and Cap 1 corrected the value to 21 Deg.

  FO1 copied the 197.5 tons value from the FMC, and when he saw Cap1's iPad OPT screen, showing 197.6 tons, he modified his OPT accordingly.

When entering the gross weight he noticed the unreasonable difference between his previously entered ZFW value and the gross weight value, he said that something appears “strange”, did not elaborate and corrected his ZFW to the value he saw on the captain’s OPT.

Each crewmember performed the calculation. The results were identical (though wrong) and Cap 1 entered the data to the FMC and MCP.

There is a dual failure mechanism in this process, both active and latent. The active failure is entering a wrong value, which is not reasonable for a long-range flight and not noticing the error. The latent failure is in FO1’s noticing that something was strange, and even stating it, but without verbalizing what was strange. The captain did not try to explore the issue. All this indicates inadequate communication between crewmembers, who apparently were working in harmony but actually did not conduct a mutual crosschecking, copied erroneous values, did not communicate in an open, effective manner, and did not clarify issues, which seemed unreasonable. The key for a crew to obtain a correct perception of the situation is to share information and raise doubts.

- **Latent failure – Permitted range of parameter values**

The flight management system has its rules for entering data, and some parameters have an allowable range. The allowed range for ZFW is broad – almost 80 tons, between 110.6 to 190.5 tons. Such range enables an error of tens of tons to occur within the allowed range, as has happened in this incident and in many other cases elsewhere

The B787-9, as well as other aircraft types has a system, which can determine the aircraft’s CG, and monitor the trim calculation relative to the allowed green band.

Nowadays there is no system in transport category aircraft, which can autonomously indicate the aircraft weight, either by accurate weight measurement or by an approximate measurement (Which will narrow the allowable band for entering weight data), and thus prevent large weight errors by crews.

Had such system been available, it could prevent accidents, which have already happened and most probably it would have prevented the subject incident.

- **Latent failure – Inexperience in aircraft type**

  All crewmembers assigned to this flight had little experience on this type aircraft.

  - The checker captain completed his conversion a month and a half before the incident and assigned as a checker shortly thereafter. Although this was his 17th flight on the aircraft, he acted as a pilot in command only on seven of those flights, and this flight was for him only the 2nd as a PM during aircraft preparation and takeoff.

    Note: Per the Air Regulations and the company procedures, the pilot in command should remain in his seat for all critical phases of the flight and allowed to leave for rest only at cruising altitude. Hence, a captain who does not act as PIC does not really accumulate hands on experience for the critical phases of the flight.
  - The other crewmembers had very little experience in the type.
  - FO1, who was on a check ride, had his previous flight 8 days prior to this flight. When training on a new aircraft type, there may be significance to acquire proficiency by continuous flying.
  - Meagre experience on an aircraft type requires much more attention by each crewmember to the various tasks in the cockpit, whether basic or complex tasks. This in turn increases the workload of the crewmembers.
  - The increased workload on the crewmembers' attention is increased further when it is a training/check ride.
  - The crewmembers did not "live the numbers". Each value used in the aircraft has reasonable range and a reasonableness criterion. Since the whole crew was not experienced in type, and combined with other background factors, none of the crewmembers, who were all in the cockpit during start and takeoff, has noticed that speed and thrust values are not reasonable and are by order of magnitude lower than typical value for a long-range flight.

- **Latent failure – Disrupted procedures**

  Cockpit preparation in a consistent and orderly manner as specified in the FCOM and OMA is a primary tool in the crew's team work, for preventing errors or for capturing errors committed.

  The crew arrived at the aircraft when the flight was already "closed", namely weight and balance data, number and distribution of passengers, cargo and baggage were known and checked. After a flight's closure, a load sheet is issued to the crew. The sheet is first sent via ACARS to the on board printer and subsequently several hard copies are delivered to the aircraft. The active crewmembers jointly review the sheet, the captain signs it, a copy remains with him and the rest are returned to the station's representative.

  Normally the crew uses the dispatch documents for preparing the initial parameters for the aircraft systems. Then the final load sheet arrives. The crew then checks the previously entered initial value and corrects it according to the final value.

  Per the FCOM the initial values should be prepared during the PREFLIGHT PROCEDURE, and then then reviewed and updated during the BEFORE START PROCEDURE.

  In reality, the updating is not done as a part of the BEFORE START PROCEDURE (i.e. after the captain's request to start the process) but rather close to the time of arrival of the load sheet to the aircraft, while being reviewed by the active crew. At this point, the crew is supposed to compare the load sheet data to the flight plan requirement (fuel) and to the aircraft systems information (fuel, weight).

  In this case, since the system was set up front based on final values, the crew did not have the additional stage of checking and updating, in which the crew would have probably detected the error.

- **Latent failure – Inadequate situational awareness, crew lack of communication and lack of crosschecking**

  Cockpit preparation was done by the active crewmembers. Cap1 acting as PM prepared the systems, FO1 prepared the cockpit as a PF.

  In order to assist them FO2 went out for the walk around and subsequently signed the fueling form. Cap 2 checked the aircraft technical logbook and was then at the cockpit for a short duration.

  The perception of the situation by each of the crewmembers was deficient in several aspects:

  - When Cap1 was calling out the values from the load sheet, FO1 was holding his own copy and was supposedly reviewing the sheet with him. Actually, according to FO1's testimony, he did not internalize and did neither effectively follow the values called out by Cap1, nor their entering to the system, which was done as is normally the case concurrently with the calling out. In reality he was focusing on other parameters and comments on the sheet and did not follow the captain's actions. Cap1 was under the impression that FO1 was accompanying him, while in reality FO1 was "present absent".
  - The fact is that cap1 entered a wrong value; FO1 did not notice it, did not even hear the captain mention his error and did not follow its correction attempt.
  - Cap1 noticed his own typing error and said so. Cap2 heard him saying it and saw him making a correction, but did not see the wrong value, whether and how it was corrected.
  - At the performance calculation process, the fact that FO1 copied the weight data that he saw on Cap1's iPad has virtually eliminated the significance of computing on two separate devices for redundancy purposes.
  - During performance calculation, FO1 did notice something strange with the data, mentioned it but "corrected" it himself instead of elevating the issue to the crew.
  - FO2 signed the fueling form without FO1 being aware of it, though it was FO1's duty to do so.

- ❖ Throughout these stages, there was supposedly a teamwork, but actually, each crewmember was functioning individually without an effective crosschecking. Cap1 said he had a mistake but did not clarify what it was. It may be natural for a person to err in a digit and promptly correct it. It happens occasionally and mostly does not lead to serious consequences. On the other hand, when a crewmember (in this case FO1) detects something, which appears unreasonable, does not share the information with the other crewmembers, and they do not inquire about it – It is inadequate crew communication.

- ➢ **Latent failure – Spatial orientation and misperception**

  Humans are "fed" by sensory feelings. Crewmembers rely on their senses like anybody else, but they also have a synthetic image of their situation by mean of the aircraft instruments. One of the criteria for aborting a takeoff is "Abnormally Slow Acceleration".

  It turns out that a crewmember's ability to detect a slow acceleration during the takeoff run is limited, even more so at night. FOQA data indicated that the aircraft accelerated from 0 to Vr of 154 knots in 41 seconds. On a flight with similar characteristics (same aircraft, similar weight and correctly calculated data), the aircraft has reached 175 knots in 41 seconds. None of the incident's crewmembers noticed the slow acceleration. Later on, none of the sluggish aircraft response to the pilot's pulling of the column, the slow raising of the nose and the long time from Vr to the POSITIVE RATE callout has caused any of the crewmembers to raise any doubt, which could have led them to any action, such as increasing thrust.

- ➢ **Latent failure – Lack of crosschecking versus objective data**

  Checking against objective data is an important element of flight safety. Actually, it is desirable to monitor data from at least two sources, as is mentioned in the company's procedures.

  Data checking in this flight and in the B787 fleet in general was lacking in the following aspects:

  - ❖ B787 fleet does not provide the crew with any reliable data checking versus another source.

- The FMC does not calculate takeoff performance. Computation by the OPT installed in the EFB is conducted in the same way as is done in the application installed on the iPad: Basic data, including weight are directly copied from the FMC data. Computation results are transferred to the FMC and approved by the crew.
- El Al policy does not make use of this option, computations are made by the OPT application installed on the iPad and are entered to the FMC by the crew.
- A computation by two crewmembers on two separate iPad devices seems to be a crosschecking but is not necessarily so. Once both crewmembers use the same values, their respective results will be identical. If one value used by both pilots is wrong, both results will be wrong, though identical. This is what happened in this case.

There are additional ways for crosschecking versus another objective source:

- Obtain data in hard copy from the dispatcher, who is anyway conducting dispatch calculations before every flight.
- Obtain data from the dispatcher via a data link.

Crosschecking weight and balance data:

- Crosschecking weight and balance data Vis a Vis dispatch documents and aircraft systems is supposed to be done during the BEFORE START PROCEDURE. In this case, the crew did use values from the load sheet, but made a mistake in entering it and did not detect the error.
- Weight and balance data from external source. Nowadays the crew enters the PERF INIT data from the dispatch documents or the load sheet. Receiving the data via a data link, uploading, updating and confirming them can be a reliable method for crosschecking, which currently does not exist in El Al's procedures, nor is the communication infrastructure available.

Crosschecking trim value:

- On some aircraft types the trim value is presented on the OPT, the FMC and the load sheet, and thus the values can be compared. The B787 fleet does not have a line for entering CG MAC into the OPT and the OPT does not calculate trim setting.
- Practically, a monovalent comparison of the FMC value and the load sheet value is not possible, due to their different calculation methods.
- According to the OM A these two sources should be compared, but a subsequent note states the results will not necessarily be identical, due to the 777/787 thrust reduction method.
- Per Boeing's policy, the trim value to be used should be the one from the FMC.
- A deviation of one trim unit to any direction will not necessarily be noticed by the crew and apparently will not affect the takeoff safety. However, had there been a reliable source for comparison and the resultant value would have been different by one unit from the value listed on the load sheet, it would have directed the crew to checking the cause and maybe to detecting the error.
- Incidentally, in this case, the crew got a trim value similar to the load sheet (5.5 vs. 5.4), due to the combination of the wrong weight they entered and the large thrust reduction.

Other data crosschecks:

- The FCOM operating procedures, in the context of cockpit preparation, have no stage for checking the VNAV pages data. VNAV pages data are mostly a result of values entered in other pages. The planned cruise altitude is entered in the PERF INIT page. Airspeeds for climb, cruise and descent are an outcome of weight, wind, COST INDEX, etc. Yet many crewmembers do check these pages during cockpit preparation. The optimal, recommended and maximum cruise altitudes can provide an insight to aircraft performance and its compatibility with the flight plan. The crew on this flight only detected the weight error because of unreasonable optimal cruise altitude on the VNAV CRZ page. This page was checked during climb. Had it been reviewed on the ground, the weight error may have been detected sooner.

- FCOM procedures state that the PF should crosscheck the data entered by the PM. It does not mention a crosschecking method and which pages should be checked. Data pages' checking is done in a sensible sequence, mostly through skipping by the R6 key. Reaching the PERF INIT page requires passing via the INDEX. It happens that crewmembers omit checking this important page.

- **Latent failure – Risk mitigation steps during B787 fleet establishment risk management**

  Establishing a new fleet, such as El Al's B787 fleet is a potential source for numerous risks. One risk area is the inevitable assigning of crews, which completely consist of pilots lacking experience in the aircraft type. Despite the pilots' prior experience, their lack of experience in type might result in missing unreasonable items and in excessive workload, compared the workload in a familiar type.

  The fleet establishment included several risk management processes. They dealt, among other things with crew qualifications, but mainly focused on individual experience and not on the overall crew.

  The outcomes of a risk management process are the risk assessment and the determination of means for reducing, mitigating or eliminating the risks.

  Regarding qualifying B777 pilots on B787 aircraft (both aircraft operated under same type rating), the question "Is the training program sufficient?" was answered in the risk management process summary by stating that El Al is at minimum level accepted worldwide. A mitigation step determined that there will be a 3rd period of FFS training (one above the minimum) and that the first flight for a pilot converting from the B777 will be in the presence of a checker. The risk assessment regarding the probability and the intensity of the occurrence of an event was "Low". It was determined that the issue will be evaluated by enhancing supervised flights at the initial period and by detailed tracking of FOQA data. Specific parameters for such tracking were not defined.

Note: FOQA system functioning has been partial since the fleet establishment. Key parameters and sometimes data of complete flights cannot be extracted from the system, due to technical difficulties related to the aircraft and its data package output, which do not depend on El Al. This issue has also affected the investigation.

Few months prior to the fleet establishment, it turned out that that company management and the pilots union did not reach an agreement regarding operation as an integrated B777/B787 fleet. The B787 fleet was established as a separate fleet, with pilots from all other fleets converting to the new type.

Thus, a situation was created where some pilots go through a long and extensive conversion, while the other pilots coming from the B777 fleet are only going through a brief differences course.

There was no revised risk management, nor means for mitigation a complete crew management, considering that they all had little experience in the B787 and most of them did not even have B777 experience.

In the fleet’s initial period of operation, all of the setup team and the converted pilots were coming from the B777 fleet. Fleet management decided to set longer pick up times, 2:30 instead of 2:00 hours as was common in other fleets for night flights. Fleet management also directed that all crewmembers would participate in the critical phases of the flights, including cockpit preparation and performance calculation.

The fleet’s character became different from the anticipated character. A large portion of the converted pilots came from different fleets and from aircraft with different characteristics.

Crew combinations came up, which would not have existed in a typical conversion from one fleet to another, including all crewmembers being inexperienced. This was the case in this flight, except for the pilot in command, where the only reason for him not defined as “inexperienced” was his conversion from the B777 fleet. He was additionally assigned as checker on this flight.

Such scenarios may be inevitable in a new fleet, but mitigation measures are necessary. A risk mitigation measure set by the fleet was to converse with every checker prior to conducting a check ride or an initial operating experience flight.

Such a conversation should, among other things review issues that surfaced in operating experience flights. Following this flight captain qualification as checker in the fleet, such a conversation did take place, but did not relate to this particular flight. Another measure was to review of crewmembers combinations considering their accumulated experience in the type. According to the chief pilot, the crew assigned to this flight was considered problematic, but it was approved in view of both captains' experience and their record in senior positions in the flight operations division.

The earlier pick up times were not changed. The requirement for all crewmembers to be present during critical flight phases and during performance calculations is not recorded as a mandatory procedure and is not necessarily conducted.

- **Latent failure – Time pressure on late night flight, near airport closure**

State of Israel Ben Gurion airport is several flight hours away from Europe and about 12-15 hours away from North America and Far East destinations.

Commercial scheduling considerations resulted in a situation where a fairly large number of long range flights are departing BGN at night, just prior to 01:40 a.m., when the night curfew begins. A flight delayed beyond the curfew time might be delayed until next morning, which will cause great inconvenience to the customers, schedule disruption, missing connecting flights, etc. For flight crews in such cases, and when the crew is not replaced, it implies stretching of duty times to near the limits. On longer flights a delay might cause exceeding duty time limits and hence a crew replacement.

The two hours prior to airport closure include at least nine flights to North America by El Al, AA, Delta and United. There are additional numerous flights to destinations in Europe and the East.

Time pressure is one of the key factors causing incidents and accidents. This type of pressure characterized the subject flight. The airport night closure itself and the policy of reducing special permits for deviations are a factor increasing the risk for an incident or accident stemming from time pressure.

- **Latent failure – Pressure due to short turnaround**

  On top of the inherent time pressure on a flight scheduled to depart 40 minutes before airport closure time, there is the factor of aircraft turnaround time following its arrival from a previous flight. El Al's operations schedule is often matching the arrival from Hong Kong to the departure to Newark. The incoming flight is prone to delays for various reasons, as was the case on this flight. A late arrival causes a turnaround time substantially shorter than standard and imposes pressures on all involved. On this flight, the working arrangements have changed significantly. The aircraft was late to the gate, so the crew boarded it with the remaining time much shorter than standard. Instead of receiving a neat and tidy aircraft, the crew entered an aircraft during cleaning, stuffing and loading. The whole system was under immense pressure to depart before airport closure. Such pressure might cause errors and disrupted processes.

- **Latent failure – Distractions**

  Distractions are one of 12 primary factors contributing to aviation incidents and accidents. Distractions have an accumulative effect. One can never determine which of the distractions has led to a crew error.

  This flight included several types of distractions, some of them "usual" and some unique to this flight.

  "Usual" distractions:

  - Discussion with ground technician regarding final fuel quantity
  - Signing the fueling form
  - Weight and balance – receiving the load sheet via ACARS and subsequent entry of the station representative with documents, checking and signing
  - Signing the FLAR book
  - Cabin crew entries to the flight deck
  - Distractions due to presence of additional crewmembers in the cockpit.

Unique distractions:

- ❖ Tight schedule, handling a permit for a late departure (after airport closure)
- ❖ Short turnaround
- ❖ Holiday flight and dealing with service passengers
- ❖ Check ride.
- ❖ Means for reducing distractions may be:
- ❖ Finalizing the fuel quantity at the briefing, without real time modifications
- ❖ Cancellation of the requirement to sign the fueling form
- ❖ Receiving and signing the load sheet via ACARS
- ❖ Improvement of procedures regarding service passengers in general and holiday flights in particular, to reduce the need for the crew, especially the captain, to deal with it in real time.

➢ **Latent failure – Fatigue and degraded performance on night flights**

Late night flights are prone to lower than normal physical and cognitive performance, due to the effects of the biological clock. Main known effects are on alertness, vigilance, memory and reaction time.

A crewmember should sleep during the day preceding a night flight. The ability to sleep during daytime, and sleep quality, are also adversely affected by the biological clock, as well as by other environmental factors.

Fatigue can have an accumulative effect and lead to degradation in a crewmember's mental and cognitive fitness, without him becoming aware of it.

The pilot in command has performed a round trip night flight to Rome with a double crew, the night before this flight. Local departure time was 01:13 and arrival at 09:28. Duty time on that flight was less than 10 hours. The legally required rest time per the Air Regulations was 8 hours. The time interval between the 09:28 chock time of the Rome flight and the subsequent 01:00 scheduled departure time to Newark was 15:32 hours. After deducting the two travel times between the airport and his home, the captain had 12 rest hours, which are 4 hours more than the regulatory requirement. He did use part of these 4 hours for resting. The captain did not report fatigue as a possible cause for his error.

Fatigue, normal or accumulative, cannot be attributed nor ruled out as the cause for the captain's two errors in data entering, which he missed, for an additional temperature error and for the lack of alertness to other parameters being unreasonable. The other crewmembers also did not report fatigue or any other functional issue, but fatigue cannot be ruled out as factor, which affected their performance.

- **Latent failure – Crewmember's mental/psychological state**

  A crewmember, like any other person, might be thrown into a period of mental stress because of economic crisis, death in the family, illness, domestic crisis, national crisis, etc.

  Crewmembers can also be subject to stress due to labor relations, professional relations in the organization, hierarchy, etc.

  The affected crewmember is not always aware of the stress effects on his performance. Other crewmembers are certainly not aware of issues affecting their colleague. Following events, which were attributed to mental stress with a professional background, El Al in the past revised its training and testing procedures and established a discrete entity for supporting crewmembers.

  In the wake of the suicide of German Wings pilot in March 2105, world airlines and pilot unions have established support systems for crewmembers in distress.

  The Israeli airline pilots association established the REUT program (Hebrew acronym, standing for support and assistance network among pilots). Member pilots who feel any kind of distress can obtain discrete support by qualified colleagues and by professionals. The program is in its initial phase and is already supporting several union members.

- **Latent failure – Summary of analysis per the Swiss Cheese model**

  This flight included a cumulative effect of active and latent failures, which eventually led to a serious incident.

  Note: Active failures are those, which actually caused the incident to happen. Latent failures are at the background, their effect is cumulative and it can neither be proven nor be disproved what was the impact of a single one of them on the incident.

  The following list summarizes the failures, active and latent, not necessary in their order of importance:

- Cap1 entered wrong value to the flight management system and re-entered the same wrong value.
- FO1 did not perform effective crosschecking over data entered by Cap1.
- The active crew made performance calculations, based on a wrong value.
- Broad range of values for entering data, lack of self-weighing system.
- All crewmembers had little experience in the aircraft type.
- Disrupted working orders.
- Inadequate situational awareness and lack of crew crosschecking.
- Misperception.
- Lack of crosschecking versus objective data.
- Ineffective risk management during the B787 fleet establishment, regarding the issue of a complete inexperienced crew.
- Time pressure due to short turnaround time, peculiar to this flight.
- Time pressure due to airport night closure, which is typical for night flights at BGN.
- Distractions during flight preparation, some of which were unique to this flight.
- A night flight, at a time when the biological clock effects might cause degradation in performance.
- Fatigue.
- Potential distress of a crewmember.

2.2.2 Analysis per TEM (Threats and Errors Model)

- **The threats** – El Al and the crew did not appropriately tackle the risks at the organization level and at the crew level:
  - Did not set mitigating measures regarding crew composition and the crewmembers inexperience in the aircraft type.
  - Dispatch with a short turnaround time just prior to airport closure.
  - Inherent distractions in the company normal operating procedures.
  - Additional distractions peculiar to this flight.
  - Fatigue, working at night.
  - Lack of data crosschecking at the procedural level.

- **The error** – the crew did not prevent the error and did not detect it after it occurred:
  - The captain entered a wrong value. Typing error is not unusual and can happen to any person at any condition.
  - The FO did not monitor the entering of the wrong value although he participated in the review of the load sheet.
  - The captain noticed his error and intended to correct it but in reality has re-entered the same wrong figure. Such an error can be attributed to fatigue, lack of concentration, workload, pressure, etc.
  - The FO was not aware of the supposed correction process and did not monitor it, despite being in his seat.
  - The other captain in the cockpit was aware of the process but did not detect that the error has not been corrected.
  - Note: The second captain is not part of the active crew and not a part of the data monitoring.
  - The crewmembers copied each other's parameters to their performance calculation applications, so that they got identical, but erroneous results.
  - The FO detected unreasonableness of the data and even mentioned it, but replaced his previous, correct value by a wrong value from the captain.
  - The crew did not discuss what seemed unreasonable to the FO.
  - None of the crewmembers has noticed that the calculated values were not reasonable for a long-range flight.

- **Undesirable aircraft state –** the aircraft departed based on calculated takeoff performance, low engines thrust and low speeds:
  - The aircraft accelerated slower than required. The crewmembers did not detect it. It should be noted that it is difficult for crewmembers to detect acceleration variations in darkness, especially considering their inexperience in the aircraft type.
  - The aircraft was sluggish in rotation, lifted off the runway at a higher than normal pitch attitude and only after gaining additional speed. The crew did not detect it and did not attribute it to the performance computation error.
  - The crew did detect the error retroactively, only upon reviewing cruise performance.
  - A tail strike accident was only prevented by the aircraft smart flight control system.

2.2.3 Analysis by Failure Barriers theory

- **Regulatory barrier**
  - The aircraft had airworthiness certificate.
  - All crewmembers were qualified and with adequate type ratings.
  - All crewmembers had sufficient rest time according to the Air Regulations.
  - The aircraft manual was approved and the operating procedures were approved by CAA-I.
  - B777/B787 aircraft types are considered similar types, hence converting from B777 to B787 consists of a brief differences course and there is no period during which the converted pilot is considered “inexperienced”.
  - A check captain who converted from the B777 fleet may be qualified as a checker in B787 fleet with neither an “inexperience period” nor an accumulation of experience on routes, as is common in conversion to a different type fleet.

  The regulatory barrier did not function.

- **Technology**
  - Aircraft systems provided no visual or other warning of the risk.
  - The aircraft flight control system designed to prevent tail strike has reduced elevators response to the pilot's pulling of the column and thus led to the aircraft lifting off at a substantially higher speed than the calculated speed and prevented the tail strike.

  The technology barrier did function and prevented an accident.

- **Processes**
  - Cockpit procedures are based on philosophy and operations policy, are supposedly emphasizing the critical segments of a flight.
  - The procedures are orderly, published and crewmembers know them well.
  - Practice does exist at the pilot level and the crewmember level.
  - None of the above prevented one crewmember from making a serious mistake, which was not detected by him or by his partner in the active crew.
  - At the cockpit preparation phase, the crew is lacking means for crosschecking some of the parameters versus system data or parameters from an independent source.

  The processes barrier did not function.

- **The personal dimension**
  - The crewmembers were under a system of pressures, weaknesses, fatigue and mental stress, and they probably were not aware of its effects.
  - The fact that on the morning of this flight, the captain has landed with a previous night flight may have had a fatigue effect of which he was not aware.
  - The check captain had limited experience in the aircraft type and yet had to check a FO, a fact that had effects of pressure and mental load, of which he was not aware.
  - The FO under check was confident of his success but was affected by additional mental burden. His will to succeed sometimes made him focus on somewhat marginal items during critical stages, such as Notes at the bottom of the load sheet and inattention to weight values and to their entering in the systems.

- Being a holiday flight, accompanying family members created additional background stress.
- Crewmembers should develop awareness of stress situations to which they are subjected, and sometimes even externalize them. For instance, stating “Pay attention, this is my first flight in a month, keep an eye on me” is a sentence indicating self-awareness and should encourage the crewmembers to perform more effective and strict monitoring should increase the awareness of the whole crew to its weaknesses. Such a statement coming from a captain may create openness within the crew.

The personal dimension barrier did not function.

- **Crew resource management**
  - Teamwork is based on rules specified in the manufacturer and operator’s manuals.
  - Each crewmember goes through basic training and subsequent periodic workshops.
  - Effective communication and crosschecking are important keys for teamwork.
  - On this flight, each crewmember had a different perception of the overall crew operation. At times when crewmember had to work together and monitor each other - it did not happen, although on the face of it, it seemed to be happening.
  - There was not an effective crew communication during critical phases. Cap1 stated his error in a feeble voice and did not confirm that another crewmember saw and monitored his correction.
  - When FO1 detected something “strange” on the OPT screen he did not elaborate, but rather corrected himself, copying the wrong parameter from Cap1’s screen. Cap1 did not try to find out what was strange.

The teamwork barrier did not function

Summary of the analysis per the failure barriers theory

- ❖ The barriers of regulation, technology, personal dimension and teamwork – all failed.
- ❖ The only barrier, which functioned and prevented an accident, was the technology – aircraft flight control system protection against tail strike.

2.2.4 Crew fitness to continue a flight following a serious safety event

- ➢ A safety event experienced by a flight crew, in particular an event involving an operational error by the crew, has a startling effect, which could subsequently impact the crew performance.
- ➢ During cruise, the crew conducted a professional debriefing and then discussed their fitness to continue the flight.
- ➢ The crew decision was that they were fit.
- ➢ There is a substantial difference between a decision to continue flying to the destination and a decision to depart for another flight following a significant safety event.
- ➢ Discontinuing a flight and return for landing following a safety event has dramatic implications on the flight crew itself and on the cabin crew, the passengers, the company, etc.
- ➢ Additionally, such a decision presents the crew with heavy workload and heavier mental stress.
- ➢ Making a decision of this nature requires the captain to consider numerous factors.
- ➢ The crew's decision to continue the flight was reasonable, considering the complexity of the alternatives and in view of having a second, fit crew on- board.
- ➢ Subsequently the crew discussed their fitness to conduct the approach. The mere execution of such a discussion improves the crewmembers awareness of their mental situation and can enhance safety. Approach and landing were uneventful.
- ➢ The mere fact that the crew discussed their own fitness demonstrates maturity and responsibility and is commendable.
- ➢ A crewmember's judgement regarding his fitness after being involved in a safety event, is less complex, but might also have implications on the crewmember as well as on his colleagues, the passengers and the company.

- These difficulties are creating a pressure on a crewmember to continue operating even while his mental fitness is questionable.
- In case of involvement in any kind of accident, a crewmember has to be cleared for flight by a certified aviation examiner.
- The examiner will not necessarily check his mental fitness.
- The involvement of a crewmember in a safety event, which was not an accident, does not require any kind of inquiry or examination.

Note: In 2010, a Qantas A380 captain experienced an uncontained engine failure in Singapore and performed in an exemplary fashion, with his crew. The company initiated a one-month leave for the captain, which he extended to 3 months, until he considered himself fit for active flying.

3. Conclusions

3.1 The event is classified as a “serious incident”, with direct responsibility of the active flight crew and contribution of organizational and management factors.

3.2 The incident began with inadequate preparation of the flight management computer, by the captain entering a ZFW value, which was substantially lower from the correct weight to the FMC, and continued with ineffective crosschecking, which did not detect the error. Takeoff performance calculation according to the wrong weight has resulted in a takeoff conducted with erroneous thrust and speed parameters, which created a real risk of tail strike or loss of control after liftoff, during initial climb and during flaps retraction.

3.3 The flight control system’s feature, of reducing elevator authority to prevent tail strike, worked and it is highly probable that it prevented an accident. Elevator deflection angles reduced immediately upon raising the nose and the liftoff, despite the continued and even increased pulling aft of the control column. Consequently, the actual tail clearance did not exceed the minimum theoretical value. The delayed raising of the nose has contributed to aircraft gaining speed prior to climbing and thus prevented a stall or loss of control.

3.4 The late arrival of the aircraft from its previous flight resulted in the crew’s arriving very late relative to the usual reporting time, while the aircraft was still being cleaned, prepared, refueled and stuffed. A narrow period prior to the airport closure for takeoffs has introduced a pressure factor to the crew’s functioning. A final load sheet was provided to the crew for review immediately upon their arrival to the airplane. At the first stage of cockpit preparation, the crew has entered final weights to the flight management computer, and not initial planning parameters as is usually done. Consequently the crew skipped the stage of checking and updating the previously entered parameter versus a final value, a stage done by every crew on every flight and is listed in the FCOM.

3.5 While reviewing the final load sheet, together with the first officer, the captain, acting as the PM entered a ZFW figure, which was 40 tons lower than the correct weight. The FO did not monitor the captain’s action and did not detect the captain’s error when it occurred.

3.6 The captain promptly noted his mistake and mentioned it, but it is highly probable that while trying to correct it he actually entered the same wrong figure. The first officer did not hear it and was not aware of the correction attempt. The other captain, who at that time was in the cockpit, heard the captain mentioning his error, saw him make a correction but in reality did not see that the wrong figure was again entered.

3.7 The first officer, acting as PF, did not perform effective cross checking of the data entered by the captain while checking all entered parameters, in accordance with operating procedures, in particular the captain’s error.

3.8 The two active crewmembers were in a singular mental fixation during the calculation of takeoff data. Although in the power selection line on the OPT they entered the correct power corresponding to a takeoff weight higher than 220 tons, they did not notice that the gross weight copied from the flight management computer, a weight which they entered in an adjacent line on the OPT, was substantially lower. The two crewmembers did not notice until the climb phase the fact that the gross weight was substantially lower than both the planned weight and the typical takeoff weight for a long-range flight.

3.9 The captain also copied the wrong ZFW from the FMC onto the OPT. The first officer, who earlier entered the planned ZFW into the OPT, noticed that there is a small and illogical margin between the ZFW he entered initially and the gross weight value which he first copied off the FMC and then corrected according to the captain’s figures. The first officer stated in the cockpit that something seemed “strange” to him, did not elaborate and modified the ZFW value to the wrong value, which he saw on the captain’s OPT. The captain heard the first officer saying that something seems strange but did not clarify the issue with him. Communication between the crewmembers during the performance computation was inadequate. Open communication and raising doubts could at high probability, have led to detecting the error and correcting it in advance.

3.10 Conducting the performance calculations, for a weight, 40 tons lower than the true weight, resulted in takeoff speeds and engines thrust setting substantially lower than required for the true takeoff weight and lower than typical values for a full airplane on a long-range flight. It is probable that inexperience on this aircraft type, of both the active crew and the augmenting crew who were at the cockpit during takeoff, has contributed to the fact that no one has noticed that the data are substantially out of the reasonable probability criterion.

3.11 Takeoff roll acceleration was significantly lower than usual. The aircraft reached V1 speed, which was 15 knots lower than the speed appropriate to the weight, at a point only about 100 feet from the correctly calculated point, due to the fact the slow acceleration was offset by the low V1. None of the crewmembers noticed the slow acceleration. There is a difficulty in perceiving acceleration variations in darkness.

3.12 Under an aborted takeoff at V1 scenario, the incident aircraft would have succeeded in stopping on the runway, because the decision point was approximately the same, though with a substantially lower decision speed. Under a scenario of engine failure at V1 and continued takeoff, it is highly probable that it would have not safely lifted off the runway, and if a lift off was accomplished the climb performance would have been insufficient to safely complete the takeoff, unless the crew would have increased the operating engine thrust to full.

3.13 The rotation speed computed by the crew was lower than Vmu and was approximately equal to the aircraft stall speed. Therefore, the aircraft only lifted off after gaining additional speed. Upon reaching the wrong rotation speed, the FO began pulling the column aft and the elevators responded accordingly. Aircraft response was sluggish, the nose raised only after reaching sufficient speed and became airborne at a pitch attitude significantly higher than usual and climbed at slow rate. Upon lift off, the elevators angle reduced for about 4 seconds, because of the flight the flight controls tail strike protection feature activation. This was sufficient to bring the smallest tail clearance to 29.3”, not exceeding the minimum defined in the aircraft manual.

3.14 Continued climb to an altitude of 1500 feet AGL was conducted at the reduced takeoff thrust, at lower than usual rate of climb and at an airspeed slightly lower than required for the actual weight, but not to an extent, which significantly affected the maneuver margin.

3.15 Flaps retraction procedure was executed based on slower flaps maneuver speeds than required for the actual weight. Although the maneuver margin was affected, in particular during retraction from flaps 1 to UP, no hazardous increase in angle of attack was observed and the process was completed safely.

3.16 While climbing through about 20,000 feet the crew checked the cruise parameters and detected the error – the recommended FMC altitude was about 38,000 feet, which seemed too high and improbable to them for an initial cruise altitude on a long-range flight. The maximum altitude at which the aircraft could be operated under the prevailing atmospheric conditions and the actual weight was lower than the recommended cruise altitude, which could not be climbed to. The error was corrected promptly in the FMC.

3.17 The first officer under check felt confident about his success and the checker inspired a comfortable atmosphere, but it can be reasonably assumed that being a check ride did contribute to increasing the mental workload on the first officer on one hand and on the captain on the other hand, especially considering the latter's low experience in the B787 fleet.

3.18 The crew inadequate teamwork has manifested itself in lack of coordination, lack of cross checking and flawed internal communication. Although the crewmembers felt good about it, it turned out that actually their perception of their cooperation was incorrect.

3.19 Night departures, during hours in which the physical and cognitive performance are impaired, have a potential for human error caused by the biological clock effects. Any crewmember embarking on a night flight is subject to such effects, but not necessarily aware of them. All crewmembers including the captain, who has operated a flight the previous night, have had sufficient rest time beyond the minimum required by the Air Regulations, yet the impact of regular or accumulated fatigue cannot be ruled out.

3.20 The discussion conducted by the active crew during the cruise, regarding their qualification to continue the flight was appropriate and the decision to continue was reasonable. The additional discussion regarding their ability to conduct the approach was also appropriate. Their decision to continue was reasonable, although it is possible that transferring command, cancellation of the check ride and transferring the approach to the augmenting crew could have been a safer alternative.

3.21 El Al's operating procedures, B787 fleet included, have no definition for cross checking of weight data and performance calculations versus objective data from external sources. Performance computation on two iPad devices does not consist effective cross checking, because both crewmembers might be using identical parameters, yielding identical yet potentially incorrect results.

3.22 El Al's communication infrastructure between aircraft systems and the ground systems does not support transmittal of weight and performance data to the aircraft via a data link. Had such network been in use and the company's operating procedures would mandate receiving weight and performance data by datalink, it is highly probable that the error would have been prevented.

3.23 The flight crew was properly qualified and held the licenses and ratings required by the Israeli Air Regulations for conducting the flight. However, all crewmembers assigned to this flight had less than one and a half month experience on the B787. All crewmembers were formally defined as "inexperienced", except for the captain who was not defined as such because he has converted from the B777 fleet. Crewmembers' inexperience with the aircraft they are operating might lead to increased workload, to additional mental pressure and reduced capability to detect unreasonable flight parameters, in particular when they are subjected to time constraints as was the case with this flight.

3.24 The aircraft was serviceable and all its relevant systems functioned properly.

3.25 El Al's risk mitigation process conducted when the B787 fleet was established has not been sufficiently effective to specify means for reducing risks in flights manned by crew combinations having little experience in the type. The implemented risk mitigation processes were, initially based on all crewmembers being converted from the B777 fleet, i.e. a similar aircraft with the same type ratings. These processes were not properly revised when there were changes in the B787 fleet and in its crewmembers' conversions.

3.26 One of the risk mitigation measures defined upon the establishing of the fleet was pilots' performance tracking by the FOQA system. Such tracking is not sufficiently effective, because it is focusing on a narrow aspect of the flight, the aircraft operation at takeoff and landing. It does not cover the other regimes of operation. No tracking parameters or irregular frequencies were defined. Eventually the tracking was not effective because the data from this system, since the fleet creation and until the incident date, have lacked essential details, due to incompatibility between the aircraft parameters and the ground analysis systems.

3.27 Another risk mitigation step defined for the fleet was a discussion between the fleet manager (Or chief pilot) with a checker prior to conducting a check ride or an initial operating experience flight. According to the fleet's chief pilot, such a conversation with the captain did take place few days before the incident flight. The conversation touched training flights and checks in general, but did not relate to this particular check ride. The captain was not aware of this being a check ride prior to starting the preflight briefing.

3.28 According to the chief pilot, the crew assignment was "in focus" by the fleet management because of the accumulated little experience in type, of all crewmembers, but it was decided to refrain from changing the assignment because both captains were experienced and in the past both of them had senior positions in the flight operations division. This decision was proven wrong. The fact that this was a holiday flight may have also been a reason for refraining from changing crew assignments.

3.29 Various distractions are typical to El Al operations and probably to other airlines as well. They include dealing with final fuel quantity during cockpit preparation, signing the fueling form, checking and signing the load sheet, etc. Dealing with “service passengers” is a distraction on every such flight, especially when there is shortage of available seats. It gets worse on holiday flights, which are critical for the family members. This was a busy holiday flight and 3 of the 4 flight crewmembers were accompanied by family members, a fact which may have caused a distraction to some and in particular to the captain who has the overall responsibility for operating the flight. When all of the above distractions occur within a tight time constraint, their effect is more pronounced.

3.30 El Al’s B787 fleet operating procedures have no reliable crosschecking of the trim for takeoff parameter. Mismatching trim values detected during a crosscheck will necessitate an explanation and thus support detection of errors. On this flight, the trim value from the FMC happened to be similar to the value on the load sheet.

3.31 The "Before Start" checklist has no item directing checking and calling out of the calculated engines thrust. Checking of this parameter meets the first criterion for inclusion of an item in the normal checklist, since it is a parameter critical to flight safety and there is no system monitoring it and cautioning if it happens to be incorrect.

3.32 The decision of the director of flight operations in 2012 to introduce takeoff data cards was not implemented. Had it been implemented, the subject incident may have been prevented.

3.33 Neither El Al’s procedures nor the Air Regulations have any reference to the mental fitness of crewmembers to continue active flying after experiencing a serious safety event.

4. Recommendations

The investigation concerned a serious event, which occurred on a B787-9 aircraft. Each recommendation includes background information. A topic in a recommendation related to this aircraft type might also be applicable to other types operated by El Al, or by other airlines and aircraft manufacturers. Therefore, some of the recommendations may apply to other operators and they were forwarded to review of other Israeli airlines, in accordance with Chapter 13 of the Israeli Air Regulations, so that they will review the relevance to their operations.

4.1 There is a heavy workload on the flight crew when an airplane is arriving from a previous mission and is scheduled for the next flight with a short turnaround time, especially at times approaching airport closures.

Recommendation: Review changes in aircraft scheduling to prevent tight time constraint between aircraft arrival from a previous mission and its departure for the next mission, especially towards airport closure.

Responsibility: El Al & companies according to chapter 13

Recommended Due Date: 31.3.2019.

4.2 Distractions are a known factor contributing to aviation incidents and accidents and did contribute to this incident.

Recommendation: Review means to remove distractions to flight crews during preparations for departure. Such means may include but are not limited to early setting of final fuel quantity, eliminating the requirement to sign the fueling form, automating the submittal and signing of the load sheet, improving the mechanism for handling service passengers, etc.

Responsibility: El Al & companies according to chapter 13

Recommended Due Date: 31.3.2019.

4.3 One of the factors, which can reduce the risk of computation errors is cross checking versus data received from an objective source. El Al B787 fleet has no effective mean for cross checking performance data.

Recommendation: Consider means for cross checking weight and performance data versus an external source, such as receiving from the dispatcher via data link.

Responsibility: El Al & companies according to chapter 13

Recommended Due Date: 31.3.2019.

4.4 A deviation of a stabilizer trim value, which will require an explanation, may contribute to detecting errors in weight and performance data. The B787 fleet has no means for reliable crosschecking of trim data.

Recommendation: Consider means for conducting accurate crosschecking of trim data in B787 aircraft and in other type aircraft, where applicable.

Responsibility: El Al & companies according to chapter 13

Recommended Due Date: 31.3.2019.

4.5 A serious incident and in particular one involving the flight crew's human error is a mentally startling event. It could affect the crewmember's performance for the remainder of the flight and in subsequent flights. There is no reference in literature, regulations or company procedures regarding continuation of flight or assignment to another flight following a serious safety event.

Recommendation: Formulate and include in company procedures a policy regarding continuation of flight following a serious safety event.

Responsibility: El Al & companies according to chapter 13

Recommended Due Date: 31.3.2019.

4.6 The flight crew had little accumulated experience in subject aircraft type, a situation with potential for errors. Risk mitigation steps, which were supposedly set and reportedly executed were not sufficient to prevent this incident. Such a phenomenon can also occur during future introduction of new aircraft types and crew conversions.

Recommendation: Conduct a new risk management process and formulate risk mitigation steps for inexperienced crew assignments when converting to B787 fleet.

Responsibility: El Al

Recommended Due Date: 31.3.2019.

4.7 Using a takeoff data card is common in many companies and serves to present the takeoff parameters in front of the pilots' eyes, and also as an additional mean for data monitoring.

Recommendation: Mandate using a takeoff data card, either hard copy or digital.

Responsibility: El Al

Recommended Due Date: 31.3.2019.

4.8 A review of the normal "Before Start" checklist has found that it lacks a check and call out of the takeoff thrust parameter, despite its being an essential item for flight safety, not monitored or crosschecked otherwise.

<u>Recommendation</u>: Consider adding TPR/EPR/N1 check in the before start checklist.

<u>Note</u>: Until a decision by Boeing, it is recommended that El Al will consider implementing this recommendation on its own.

Responsibility: Boeing Company

Recommended Due Date: 31.3.2019.

4.9 Following the 2004 accident where a B747 crashed after takeoff from Halifax, the Canadian investigative authority has recommended installing a takeoff performance monitoring system (TOPMS) on transport category aircraft. This recommendation was not implemented to this date. A reliable monitoring system could have detected a slow acceleration, could alert the crew and lead it to aborting the takeoff.

<u>Recommendation</u>: Install a takeoff performance monitoring system in transport category aircraft, a system that should be able to alert the crew in a timely and reliable manner of exceeding the conditions required for a safe takeoff, and should support the crew in deciding whether to abort or to continue the takeoff.

Responsibility: Boeing Company

Recommended Due Date: 31.3.2019.

4.10 The parameters entered into the flight management computer have definite ranges. Performance calculations conducted by the flight management computer, are partly based on data entered by the crew. Such parameters might be substantially in error and yet still be within the range of values set in the system.

<u>Recommendation</u>: Install a self-weighing system in transport category aircraft, a system that should be able to provide the flight management computer with exact value of the aircraft weight, or at least a value, which will enable a substantial reduction of the weight value range and will alert the crew of a significant data entry error.

Responsibility: Boeing Company

Recommended Due Date: 31.3.2019.

Sincerely

Adv. Raz Itzhak (Razchik)
Chief Investigator

Date: 26.11.2018 **Reference**: 4000-0098-2018-0013979