DUTCH
SAFETY BOARD

Erroneous takeoff performance calculation, Boeing 777

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The Hague, October 2020

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Dutch Safety Board

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N.B. This report is published in the English language with a separate Dutch summary. If there is a difference in interpretation between the report text and the summary text, the report text will prevail.

CONTENTS

SUMMARY

A Boeing 777 was scheduled for a passenger flight from Amsterdam Airport Schiphol in the Netherlands to Toronto Pearson International Airport in Canada. During the initial climb, the flight crew was informed by Air Traffic Control that probably a tail strike had occurred. The crew decided to treat the event as an actual tail strike and returned to Schiphol. After landing, it appeared that a tail strike had occurred but that the wear of the tail skid shoe was within limits and no immediate repair was necessary.

The tailstrike was caused by an overrotation of the aeroplane during the takeoff, which was the result of a lower than required airspeed at which the rotation was started. The reason for this was that the actual takeoff weight was higher than the takeoff weight that had been used for the takeoff performance calculation. Due to a human error predominantly caused by time pressure, incorrect load sheet data was supplied to the pilots. Neither the airline's loading procedures nor the cross check of data by the pilots did prevent the use of the incorrect data for the takeoff performance calculation. The interaction between human performance, the cross check of data by the pilots, the airline's loading procedures, limited systems integration and operational pressure to meet the planned takeoff time contributed to the takeoff performance calculation with the incorrect data as input.

Furthermore, in this situation of insufficient thrust setting, as a result of the takeoff performance calculation with incorrect entry data, the takeoff was performed without the required safety margins. In case of an engine failure after the decision speed V_1, the aeroplane would not have been able to continue the flight safely.

Takeoff performance occurrences are a special group within the takeoff occurrences. They are not limited to specific aeroplane types or flight operations. They stand out because of the absence of a proper warning system and because the outcome of the majority of these occurrences is without damage or loss of life. The outcome of a performance occurrence can be catastrophic though, but luckily until now most of them resulted in the aeroplane just getting airborne before the end of the runway. As the outcome of those occurrences is often without consequence, one might tend to believe that the problem is not that serious.

In March 2018, the Dutch Safety Board published the report *Insufficient thrust setting for takeoff*. This report analyses two serious incidents involving an insufficient thrust setting for takeoff. The Board recommended in this report to European Union Aviation Safety Agency (EASA) among others to start the development of specifications and the establishment of requirements for Takeoff Performance Monitoring Systems without further delay. In the first quarter of 2020, this recommendation was under review by EASA.

Investigation reports of state accident investigation agencies on takeoff performance occurrences show that in the past decades the airline industry has made efforts to improve the operational procedures to prevent incorrect takeoff thrust settings. However, these efforts have not resulted in a significant reduction of the risk, as takeoff performance occurrences are still encountered on a regular basis. Therefore it is urgent, as this occurrence once again shows, to introduce new systems that are fully integrated in the cockpit and among others provide a timely alert to flight crew when the achieved takeoff performance is inadequate for the given aeroplane configuration, actual weight and balance and aerodrome conditions. In 2018, Airbus developed a function on the A380 which is now also available on the A350, called Takeoff Monitoring (TOM), which warns a crew of abnormally low takeoff acceleration. This kind of systems should become part of the global commercial fleet.

RECOMMENDATIONS

In March 2018 the Dutch Safety Board published the report *Insufficient thrust setting for takeoff* in which it recommended to EASA to start, in cooperation with other regulatory authorities, standardisation bodies, the aviation industry and airline operators, the development of specifications and the establishment of requirements for Takeoff Performance Monitoring Systems (TOPMS) without further delay. Such a system has to provide a timely alert to flight crew when the achieved takeoff performance is inadequate for the given aeroplane configuration and aerodrome conditions, including the runway length available in case of intersection takeoffs.

At the time of writing this report the overall feasibility of TOPMS has still not been demonstrated because of the complexity of such a system. As a result, no technical specifications or guidance materials to define the operational performance of such a system have been drafted. At the same time, takeoff performance occurrences continue to occur, and therefore the development of technological solutions is still urgent. Systems detecting gross input errors and deviations in parameter settings or comparing predicted and actual aeroplane acceleration during the takeoff run are systems that are considered feasible as a first step towards a more complex TOPMS.

Reduced thrust takeoffs[1] are commonly used as a cost reduction measure. However, performing reduced thrust takeoffs introduces safety risks, such as the risk of input of erroneous takeoff parameters into the Electronic Flight Bag and/or Flight Management System as well as a reduction of the takeoff performance safety margins. The erroneous data input may lead to calculated takeoff speeds and thrust settings being lower than required, causing a flight safety hazard, because the required takeoff roll increases. In case of only minimal changes in takeoff parameters, the resulting additional cost reduction will probably also be marginal. However, changing the input data introduces the risk of erroneous entries, especially when a change is introduced last minute. Currently, there is insufficient insight in the relation between the actual cost reduction on one hand and the increase in safety risk with respect to erroneous data entry on the other hand. Also, there is no common airline policy or procedure regarding reduced thrust takeoffs and the entry of takeoff performance data. The Dutch Safety Board is of the opinion that operators need to consider the benefits of reduced thrust takeoffs against the possible safety risks, like reduced safety margins in case of an engine failure after the decision speed V_1.

1 In this report the term 'reduced thrust takeoff' is used for all takeoffs with less than maximum available thrust.

The Dutch Safety Board therefore issues the following recommendations:

To European Union Aviation Safety Agency and the Federal Aviation Administration:

To take the initiative in the development of specifications and, subsequently, develop requirements for an independent onboard system that detects gross input errors in the process of takeoff performance calculations and/or alerts the flight crew during takeoff of abnormal low accelerations for the actual aeroplane configuration as well as insufficient runway length available in case of intersection takeoffs. Take this initiative in close consult with the aviation industry, including manufacturers of commercial jetliners amongst which in any case The Boeing Company.

To International Air Transport Association:

To develop a standard policy for airlines with regard to procedures for reduced thrust takeoffs, including a risk analysis addressing cost reductions versus introduced safety risks.

To The Boeing Company:

For the existing and future commercial aeroplanes, to research on and develop an independent onboard system that detects gross input errors in the process of takeoff performance calculations and/or alerts the flight crew during takeoff of abnormal low accelerations for the actual aeroplane configuration as well as insufficient runway length available in case of intersection takeoffs.

To International Civil Aviation Organization:

To note the conclusions of this report and introduce provisions addressing an independent onboard system that detects gross input errors in the process of takeoff performance calculations and/or alerts the flight crew during takeoff of abnormal low accelerations for the actual aeroplane configuration as well as insufficient runway length available in case of intersection takeoffs.

J.R.V.A. Dijsselbloem
Chairman Dutch Safety Board

C.A.J.F. Verheij
Secretary Director

LIST OF ABBREVIATIONS

ACARS	Aircraft Communications Addressing and Reporting System
APU	Auxiliary Power Unit
ASDA	Accelerate Stop Distance Available
ATC	Air Traffic Control
ATM	Assumed Temperature Method
ATSB	Australian Transport Safety Bureau
CDU	Control Display Unit
CLCU	Centralized Load Control Unit
CVR	Cockpit Voice Recorder
EFB	Electronic Flight Bag
EICAS	Engine-Indicating and Crew-Alerting System
EPR	Engine Pressure Ratio
EUROCAE	European Organization for Civil Aviation Equipment
FCOM	Flight Crew Operations Manual
FCTM	Flight Crew Training Manual
FDM	Flight Data Monitoring
FDR	Flight Data Recorder
FL	Flight Level
FMC	Flight Management Computer
FMS	Flight Management System
KIAS	Knots Indicated Airspeed
LDW	Landing weight
LMC	Last Minute Change
MOPS	Minimum Operational Performance Standard
NOTAM	Notice to Airmen
OBWBS	On-Board Weight and Balance System
OFP	Operational Flight Plan
OM	Operating Manual
QRH	Quick Reference Handbook
RTO	Rejected Takeoff

TODA	Takeoff Distance Available
TOM	Takeoff Monitoring
TOPMS	Takeoff Performance Monitoring System
TORA	Takeoff Run Available
TOW	Takeoff Weight
TPR	Turbofan Power Ratio
TSP	Tail Strike Protection
UTC	Coordinated Universal Time
V_1	Takeoff Decision Speed
V_2	Takeoff Safety Speed
V_{MCA}	Minimum Control Speed in the Air
V_{MCG}	Minimum Control Speed on the Ground
V_R	Rotation Speed
V_{REF}	Reference Approach Speed
ZFW	Zero Fuel Weight

GENERAL INFORMATION

Reference number:	2017038
Classification:	Serious incident
Date, time of occurrence:	21 April 2017, 12.06 hrs[2]
Location of occurrence:	Amsterdam Airport Schiphol
Aircraft registration:	VT-JEW
Aircraft type:	Boeing 777-300ER
Aircraft category:	Commercial airliner
Type of flight:	Scheduled passenger flight
Phase of flight:	Takeoff
Damage to aircraft:	None
Number of flight crew:	2
Number of cabin crew:	13
Number of passengers:	343
Injuries:	None
Other damage:	None
Light conditions:	Daylight

2 All times in this report are local times (UTC + 2 hours), unless otherwise specified.

1 FACTUAL INFORMATION

1.1 General introduction

On 21 April 2017, a Boeing 777 took off from Amsterdam Airport Schiphol in the Netherlands. During the initial climb, the flight crew was informed by Air Traffic Control that probably a tail strike had occurred. The crew decided to treat the event as an actual tail strike and returned to Schiphol. After landing, it appeared that a tail strike had occurred, but that the wear of the tail skid shoe was within limits and no immediate repair was necessary.

At an early stage of the investigation, it was found that an incorrect weight had been entered in the Electronic Flight Bag[3] and that insufficiently applied takeoff power (referred to as thrust setting) probably had caused the tail strike. The Dutch Safety Board (DSB) investigated similar occurrences of insufficient thrust settings in the past and recommended European Union Aviation Safety Agency (EASA) in 2018[4] among others to start the development of specifications and the establishment of requirements for an autonomous Takeoff Performance Monitoring System.

Takeoff performance related occurrences have been taking place for many years.[5] Although most of these occurrences had no serious consequences for the involved passengers or the aeroplane, almost all of them had the potential for a catastrophic accident if the available runway length was only marginally shorter or in combination with an engine failure. The serious incident described in this report is a further example of this global problem. Airlines have made efforts to improve operational procedures for reduced thrust takeoffs in an effort to reduce the number of occurrences. These efforts, however, have not resulted in the necessary reduction of the number of incidents worldwide.

The investigation into this serious incident answers the following two questions: What caused the tail strike? What are the latest global developments regarding measures taken to reduce the number of takeoff performance related occurrences?

To answer these questions the following factual information was gathered and considered relevant.

3 The Electronic Flight Bag is described in paragraph 1.6.3.
4 Dutch Safety Board, *Insufficient thrust setting for takeoff,* March 2018.
5 Martinair, KLM, NLR, *Take-off performance incidents: do we need to accept them or can we avoid them?,* ISASI annual seminar, September 2019.

1.2 History of flight

The aeroplane was scheduled to operate a flight from Amsterdam Airport Schiphol (hereafter Schiphol) to Toronto Pearson International Airport in Canada on 21 April 2017. While the flight crew was on its way to Schiphol, the process of flight preparation and loading of the aeroplane had already started at Schiphol by a contracted ground service provider.

Preflight ground crew
For this particular route, the normal procedure was that the loadsheet[6] was provided by the airline's Centralized Load Control Unit (CLCU) in Chennai in India. At Schiphol, the loading of cargo and luggage of the aeroplane was performed by the load controller of the ground service provider after loading information was received from the CLCU. The CLCU and load controller communicated via a dedicated software application.

The CLCU of the airline sent the briefing package[7] to the ground service provider. This package arrived half an hour late. The ground service provider subsequently handed it over to the flight crew. The crew reviewed the information and provided the load controller with the final fuel figures. Meanwhile the ground service provider finished loading the aeroplane. During the passenger boarding process, the airline representative informed the load controller that all planned passengers were accounted for. The representative then urged the load controller to request the final loadsheet from the airline's CLCU to attain an on-time departure.

The load controller received the final baggage and cargo[8] weights and then sent those figures to the CLCU. The load controller asked the CLCU to provide a loadsheet on the presumption that all planned passengers had boarded. When the final loadsheet from the CLCU was received, it was discovered that one passenger had not shown up at the gate. As a result, as there was little time, the load controller made a last minute change (LMC[9]). The load controller reduced the actual weights[10] by 100 kg[11] and listed the new values manually on the loadsheet. For the actual takeoff weight the load controller wrote down 229,075 kg instead of 299,075 kg, a difference of 70,000 kg. See Figure 1.

6 A completed loadsheet contains weight and balance data pertaining to a particular flight, including the weight of the aeroplane, crew, pantry, fuel, passengers, baggage, cargo and mail. It also contains details of the distribution of this load. A check whether or not the centre of gravity is within limits should be made visible.
7 The briefing package consists of relevant information for the flight crew regarding expected weights, routing, weather, expected fuel burn and NOTAMs.
8 This is also called 'dead load': baggage, cargo, mail, ballast and equipment in compartments not included in dry operating weight of the aeroplane
9 See paragraph 1.11.2 for more information about the LMC procedure of the airline.
10 Zero fuel weight, takeoff weight and landing weight.
11 The standard weight of a passenger including luggage.

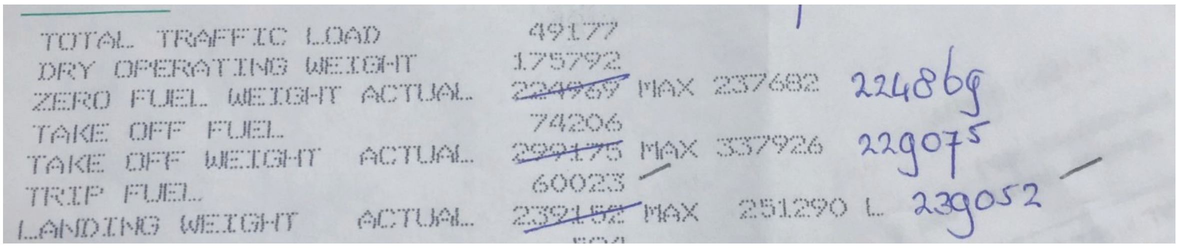
TOTAL TRAFFIC LOAD 49177
DRY OPERATING WEIGHT 175792
ZERO FUEL WEIGHT ACTUAL 224969 MAX 237682 224869
TAKE OFF FUEL 74206
TAKE OFF WEIGHT ACTUAL 299175 MAX 337926 229075
TRIP FUEL 60023
LANDING WEIGHT ACTUAL 239152 MAX 251290 L 239052

Figure 1: A part of the loadsheet with the written LMC corrections on it.

Preflight flight crew

The load controller presented the loadsheet to the captain. In the meantime, the ground crew was off-loading the luggage of the 'no show' passenger.

The captain checked the loadsheet and signed it. He then read out the aeroplane weights and relevant information from the loadsheet, while he was programming his Electronic Flight Bag (EFB). Simultaneously the first officer programmed his EFB and the Flight Management System (FMS)[12], while he was confirming the data (including the weights to be used for the takeoff performance calculation) with the captain.

After a reassignment of the departure runway and departure route, both pilots adjusted the information in the EFB. The outcome of the EFB calculations, such as optimal flap setting, (reduced) engine thrust[13], assumed temperature and takeoff reference speeds, were crosschecked between the pilots.

Takeoff reference speeds, commonly referred to as V speeds, assist pilots in determining when a rejected takeoff can be initiated and when the aeroplane can rotate, lift-off and climb away safely given the existing flight conditions. They are defined as follows:

V_1: Decision speed - the maximum speed at which a rejected takeoff can be initiated by the pilot, and the minimum speed at which the takeoff can be continued in the event of an engine failure. If an engine failure does occur after V_1, the takeoff should be continued.

V_R: Rotation speed - the speed at which the aeroplane rotation is initiated by the pilot. This speed ensures that, in the event of an engine failure, lift-off is achievable and the takeoff safety speed (V_2) is reached at 35 ft above ground level at the latest.

V_2: Takeoff safety speed - the minimum speed that needs to be maintained up to the acceleration altitude, in the event of an engine failure after V_1. Flight at V_2 ensures that the minimum climb gradient required is achieved, and that the aeroplane is controllable.

12 The Flight Management System is described in paragraph 1.6.4.
13 The term reduced (engine) thrust is explained in paragraph 1.12.

An aeroplane's takeoff weight (TOW) and zero fuel weight (ZFW) are crucial values used to determine the V speeds required for takeoff. They are defined as:

TOW: the total weight of the aeroplane at the time of initiating the takeoff roll.
ZFW: the total weight of the aeroplane excluding the useable fuel. This includes the weight of the aeroplane, the pilots, cabin crew, passengers, baggage, cargo, food and water.

The first officer entered the data from the EFB into the FMS. The zero fuel weight from the loadsheet was used to program the FMS. The adjusted takeoff weight (TOW) from the loadsheet was used for takeoff performance calculations by the EFB. The FMS takeoff reference speeds were deselected and the takeoff reference speeds, calculated by the EFB, were entered in the FMS. Afterwards, the flight crew checked the takeoff reference page on the FMS.

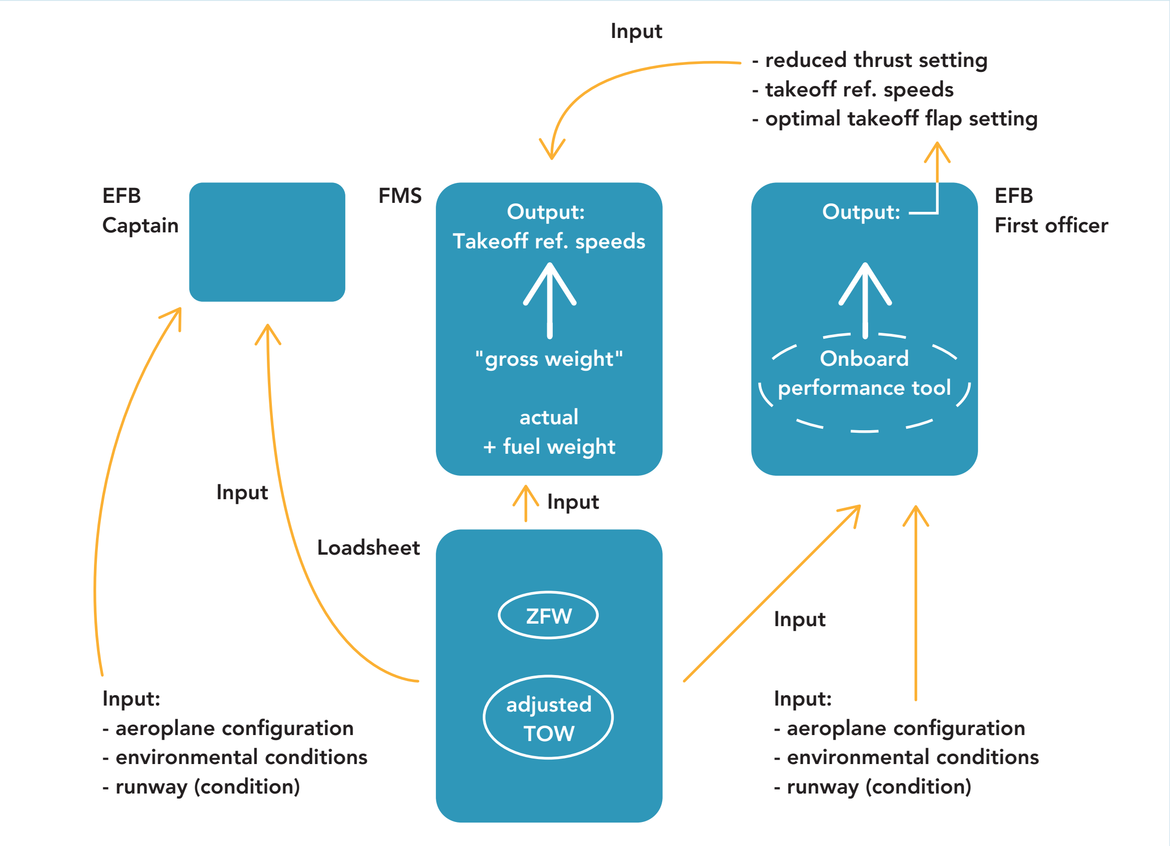

Figure 2: Schematic representation of FMS and EFB and associated operations

During the preflight phase, several issues occurred (like a door that did not close properly), that required the attention of the flight crew.

Taxi, takeoff and initial climb
After starting the engines, pushback and completing the taxi out checklist, the aeroplane started taxiing. The aeroplane proceeded to the beginning of runway 18C. Prior to the line-up on runway 18C, the crew switched off the air conditioning packs according to their 'packs-off' takeoff procedure. Subsequently the crew received the takeoff clearance from Air Traffic Control (ATC).

The captain, who was pilot flying, set the takeoff thrust, as calculated by the EFB. During the takeoff roll, the first officer, who was pilot monitoring, observed the captain's actions, checked the instruments and called out the takeoff reference speeds. When the first officer made the V_r call, the captain applied back pressure on the control column and aimed to follow the flight director pitch commands[14] on his Primary Flight Display[15] to obtain the required climb attitude.

The first officer stated that during or just after the rotation, he felt a slight pitch hesitation and a bump. These occurred without any noise and/or caution alerts being generated. The captain stated that the aeroplane was 'sloppy' on the fight controls and not behaving and accelerating as expected. Because of this, the captain limited the pitch to just below the flight director pitch bar. He did not select additional thrust.

Shortly after becoming airborne, the crew contacted Schiphol Departure. After approximately 4 minutes, the departure controller informed the crew that a possible tail strike had been observed by an air traffic controller in the tower. The flight was instructed to climb to flight level[16] (FL) 240. Approximately 6 minutes after the takeoff, a cabin attendant notified the flight crew that an unusual scraping sound had been observed during the takeoff. The flight crew requested a clearance from ATC to stop the climb at FL150. This clearance was provided by ATC.

The flight crew analysed the situation and the first officer stated that he had not noticed any unusual sounds, but had felt a slight pitch hesitation and bump during or just after the rotation. No 'TAIL STRIKE' caution was generated by the Engine-Indicating and Crew-Alerting System (EICAS). The flight crew, nevertheless, treated the event as an actual tail strike and initiated a return to Schiphol.

Return to Schiphol
The flight crew performed the *Tail strike* checklist and informed ATC about their intention to return to Schiphol. Due to the fact that the actual aeroplane weight (as shown on the FMC[17]) was above the maximum landing weight, the crew decided to dump fuel to meet landing weight requirements. After the fuel jettison procedure had been completed, ATC provided radar vectors for a landing on runway 27. The aeroplane landed safely and taxied to a parking stand.

14 The flight director computes and displays the proper pitch and bank angles required for the aeroplane to follow a selected flight path.
15 The Primary Flight Display is an instrument representing the primary flight parameters on one compact display.
16 Aeroplane's altitude at standard air pressure, expressed in hundreds of feet.
17 The FMC calculated the gross weight on basis of the inserted ZFW.

1.3 Injuries to persons

There were no injuries.

1.4 Damage to aeroplane

There was no damage to the aeroplane. The tail skid shoe was slightly scraped as a result of the tail strike (see Figure 3), but within limits as stated in the Aircraft Maintenance Manual to allow continued operation of the aeroplane. The fin of the tail strike detection system was still intact, which explains that no 'TAIL STRIKE' warning was generated in the cockpit.

Figure 3: Tail skid shoe with scrape marks.

1.5 Personnel information

1.5.1 Flight crew

The flight crew consisted of a captain and a first officer. Both were fully qualified to fly the Boeing 777-300ER.

1.5.2 Load controller

The load controller of the incident flight had ten years of experience in handling flights for the involved airline and other airlines.

1.6 Aircraft information

1.6.1 General

Manufacturer	Boeing Commercial Airplanes
Model	777-300ER
Date of manufacture	August 2007
Serial number	35164
Registration	VT-JEW
Engine model	GE90-115B1L

The aeroplane had one known technical deficiency during the incident flight, being an inoperative auxiliary power unit bleed air system. According to the minimum equipment list of the airline, the aeroplane may be dispatched in this condition. This defect has no effect on the aeroplane performance during takeoff.

At present (2020), onboard the Boeing 777 no system exists that generates a warning if the engine thrust setting is insufficient for the aeroplane's configuration and aerodrome conditions.

1.6.2 Weight and balance

Based on the loadsheet, the weight and center of gravity of the aeroplane during takeoff were within the prescribed limits. No weight and balance system was installed on this aeroplane.[18]

1.6.3 Electronic Flight Bag

The Boeing 777-300ER is equipped with two Electronic Flight Bags (EFB) integrated in the cockpit, one on the captain's side and one on the first officer's side. The EFB enables pilots to use the airport moving map application, review aeronautical charts, manuals, documents and to conduct takeoff performance calculations et cetera. Although the EFB is integrated into the aeroplane's design, its ability to exchange data with other aeroplane systems, like the Flight Management System (FMS), is limited.

The onboard performance tool, which is part of the EFB, is used for takeoff, landing and weight and balance calculations. This tool uses the takeoff weight, the runway, the runway condition, environmental conditions and the aeroplane configuration. It calculates an optimal takeoff flap setting and takeoff reference speeds (V_1, V_r and V_2) in order to meet the maximum reduced thrust setting and assumed temperature possible for a given runway and entry point on that runway.

18 VT-JEW was not equipped with pressure sensors for determining the actual weight and center of gravity.

Figure 4: An Electronic Flight Bag.

1.6.4 Flight Management System

The Boeing 777-300ER is also equipped with a Flight Management System (FMS), consisting of two Flight Management Computers (FMC). It is the primary system for navigation, inflight performance optimization, automatic fuel monitoring et cetera.

The FMS uses the calculated gross weight[19] (an addition of the weight of the actual fuel and the zero fuel weight) for the calculation of the takeoff reference speeds. This zero fuel weight has to be inserted in the FMS. In contrast, the EFB uses the takeoff weight from the loadsheet (after it has been inserted in the EFB) for the calculation of these speeds.

1.6.5 Tail strike prevention and detection

The Boeing 777-300ER features three systems to prevent and detect a tail strike:

1. Tail strike protection system.
2. Tail skid system.
3. Tail strike detection system.

Tail strike protection system

The primary flight computers of the aeroplane calculate the rate of closure of the tail to the ground during rotation. When the closure rate is too high and a tail strike is imminent, the system reduces elevator deflection in order to reduce the potential for a tail skid ground contact. The reduction in elevator deflection is limited to 10 degrees and can be overcome by the flight crew, by pulling the control column further aft. The system does not provide feedback to the control column when activated.

19 Gross weight is the total aeroplane weight at any moment during the flight or ground operation. An aeroplane's weight will decrease during a flight due to fuel consumption.

Tail skid system
The tail skid is located underneath the aft fuselage. It extends and retracts along with the landing gear. The tail skid helps to protect the fuselage from contacting the runway, thus preventing damage to the fuselage by absorbing the force of impact when the tail is about to make contact with the runway.

Tail strike detection system
The tail strike detection system consists of a small fin underneath the aft fuselage of the aeroplane. In case of contact with the ground, the fin becomes damaged or breaks off. The fin contains two electrical wires that go to the proximity sensor electronics units. If a tail strike occurs, the wires will open or short. This tells the proximity sensor electronics units that there has been a tail strike and a 'TAIL STRIKE' caution message will be presented on the Engine-Indicating and Crew-Alerting System (EICAS).

1.6.6 Flight Operations Technical Bulletin
In August 2001, Boeing issued Flight Operations Technical Bulletin 777-8, which informs airlines that there had been occurrences with Boeing 777-300 aeroplanes where tail skid contacts occurred which did not activate the EICAS tail strike warning. In some of these events, flight crews were not aware that the tail skid had contacted the ground until they were notified by ATC. In all cases known to Boeing, when the bulletin was issued, the tail skid functioned as designed and the fuselage, along with the tail strike detection system, remained undamaged.

The bulletin also provides guidance for flight crews when they are made aware that a tail strike occurred, but no EICAS 'TAIL STRIKE' message is presented. It states that flight crews of the Boeing 777-300 should continue the flight, as the tail skid has protected the fuselage from damage.

1.7 Meteorological information

The crew commenced their takeoff at 12.05 hrs. The actual weather at 11.55 hrs was:

Wind direction and speed	Mean wind 270° with 11 kts. Wind direction variable between 240° and 300°.
Visibility	10 kilometres or more
Clouds	Few at 1,200 ft Broken at 2,800 ft
Outside Air Temperature (OAT)	13 °C
Dew point	9 °C
QNH	1029 hPa
Trend	No significant change

1.8 Aerodrome information

The flight departed from runway 18C of Schiphol. The specifications of runway 18C are:

Takeoff Run Available (TORA)	3,300 m
Takeoff Distance Available (TODA)	3,360 m
Accelerate Stop Distance Available (ASDA)	3,300 m

TORA *Takeoff Run Available: The length of runway declared available and suitable for the ground run of an aeroplane taking off.*

TODA *Takeoff Distance Available: The length of the takeoff run available plus the length of the clearway[20], if provided.*

ASDA *Accelerate Stop Distance Available: The length of the takeoff run available plus the length of the stopway[21], if provided. Usually, this is the runway length available from the beginning of the runway or from a certain intersection or position.*

1.9 Flight recorders

Both the flight data recorder (FDR) and cockpit voice recorder (CVR) were read out successfully. Both the FDR and CVR recorded the entire duration of the flight until final stop.

1.10 Tests

At the request of the Dutch Safety Board, Boeing analysed this occurrence in order to indicate its severity. Boeing made calculations for two possible scenarios. First, a high speed and close to V_1 rejected takeoff and the consequence on the stopping distance. Second, an engine failure at or after V_1 and the extent of its effect on the aeroplane's performance and controllability. These calculations are further discussed in paragraph 2.2.4.

20 A clearway is an area beyond the paved runway, free of obstructions and under the control of the airport authorities.

21 A stopway is a defined rectangular area on the ground at the end of the takeoff run available prepared as a suitable area in which an aeroplane can be stopped in the case of an aborted takeoff.

1.11 Organizational information

1.11.1 Signed loadsheet procedure

The Civil Aviation Authority of India required the airline to hand over a signed loadsheet to the flight crew if the loadsheet had not been sent to the aeroplane by electronic means[22], i.e. an Aircraft Communications Addressing and Reporting System (ACARS). During the time of the incident, such a system was still in development for the airline and therefore the signed loadsheet was handed over to the flight crew.

1.11.2 Last minute change

A last minute change is amongst others defined by a change in the number of passengers and/or crew and, the amount of cargo/checked-in baggage, fuel etc., after the loadsheet has been issued. According to the procedures of the airline, permitted deviations on last minute changes on the computerised loadsheet of the Boeing 777 are:

- maximum 5 passengers and their checked-in baggage and/or
- maximum 1,000 kg cargo/baggage and/or
- maximum 5 crew and/or
- maximum 5,000 kg of fuel.

A total of two last minute changes on a computerised loadsheet is permitted, according to the regulations of the Civil Aviation Authority of India. Last minute changes must be reflected on the loadsheet and must be authenticated with a signature of approved personnel. Last minute changes must be checked by the captain to ensure that weight limits (ZFW, TOW and LDW[23]) and loading limitations are not exceeded and that the centre of gravity remains within the limits.

1.12 Additional information

Reduced thrust takeoffs

Civil aeroplanes are designed to operate from most airports at the maximum takeoff weight. Very often the maximum takeoff weight is not reached and as a consequence ample takeoff thrust is available. It is common to reduce this thrust during takeoff to reduce the wear and tear of the engines; it increases engine life and therefore lowers maintenance costs of the engine. The minimum amount of thrust required for a safe takeoff is therefore used.

> *Many aircraft are capable of exceeding the minimum performance standards required for operating at certain airports and under the existing environmental conditions. In such cases, conducting every takeoff at maximum engine thrust would place undue stress on the engines and decrease engine life. Consequently, reduced thrust takeoffs are commonly used (Australian Transport Safety Bureau, 2009).*[24]

22 This requirement applied to all airline destinations, including Schiphol.
23 Landing weight: the total weight of the aeroplane at the time of landing.
24 Australian Transport Safety Bureau, *Take-off performance calculation and entry errors: A global perspective,* Aviation Research and Analysis Report - AR-2009-052, 2011.

A downside to performing reduced thrust takeoffs involves the risk of input of erroneous takeoff parameters (like an erroneously adjusted takeoff weight, derived from a loadsheet) into the EFB and/or FMS as well as a reduction of the takeoff performance safety margins. The erroneous data input may lead to calculated takeoff speeds and thrust settings being lower than required, causing a flight safety hazard, because the required takeoff roll increases. Even with correctly calculated and entered takeoff data, the required takeoff roll length will increase, which is especially riskfull in the case of an engine failure. In case of a full thrust takeoff, the risk of erroneous data input decreases, because less parameters have to be inserted. In addition, existing safety margins are not reduced with a full thrust takeoff.

2 ANALYSIS

2.1 Introduction

In this chapter the erroneous takeoff performance calculation will be analysed. Furthermore developments in the field of takeoff performance calculations are considered in a broader context. In addition, it will be examined how EASA has followed-up on the recommendations with regard to the investigation *Insufficient thrust setting for takeoff* by the Dutch Safety Board, published in 2018.

2.2 Erroneous takeoff performance calculation

2.2.1 Loading procedures

Already before boarding of the passengers had started, the load controller experienced time pressure because the briefing package arrived half an hour late. At the same time there was the need for an on-time departure. When it became clear that one passenger had not shown up, a manual last minute change of 100 kg on the loadsheet was made. This was according to the procedures of the airline and it was felt that there was no time to request a new computerised loadsheet. Therefore the load controller amended the actual takeoff weight on the loadsheet, however this turned out to be an erroneous takeoff weight.

Research performed by NASA[25] has revealed that time pressure negatively influences human performance. The goal of an 'on time departure' of the aeroplane led to high time pressure, especially because the briefing package was already delayed. This may also have led to increased anxiety for the load controller. Anxiety is known to reduce the selective attention and working memory capacity.[26] Therefore, it is conceivable that high time pressure and the associated anxiety were factors contributing to the erroneous takeoff weight that was written down on the loadsheet.

2.2.2 Cross check procedures

The above mentioned delay took away time for the flight crew to review the operational briefing. The flight crew stated they experienced time pressure during the pre-flight process. It was felt that no time was available to pre-enter the estimated aeroplane weights from the preliminary loadsheet in the EFB and in the FMS.

25 NASA, *Stress, Cognition, and Human Performance: A Literature Review and Conceptual Framework*, NASA/TM-2004-212824, 2004.
26 Hockey, R., Gaillard, A., & Coles, M., *Energetics and Human Information Processing*, 1986.

The captain was distracted several times in his flight preparation flow. He stated that he was experiencing pressure and reached his saturation level. This created a situation in which the flight preparation process and the coordination between both pilots became less effective and vulnerable to error. The difference of 70,000 kg between the actual TOW and the TOW after the LMC correction can be considered as a large deviation.[27] The perceived time pressure may have played a role in not detecting the erroneous takeoff weight on the loadsheet.

Entering the EFB calculated takeoff reference speeds into the FMS, a difference of 10 to 12 knots with the (correct) calculated takeoff reference speeds from the FMS existed. Normally the takeoff reference speeds between the EFB and FMS do not differ more than a few knots.

Adhering to standard operating procedures, cockpit flows and checklists enables flight crews to perform under high workload. As mentioned above, the flight crew was working under time pressure. The airline had an operating procedure to program the EFB and FMS. According to this procedure (FCOM *Before Start Procedure)*, the captain has to read out loud the relevant information while the first officer programs and checks his EFB and the FMS.

In this instance, the captain read the erroneous takeoff weight and the first officer entered this incorrect number in the EFB and crosschecked it with the FMS. The first officer did not notice the difference between the stated takeoff weight of 229,075 kg by the captain and the gross takeoff weight of 299,400 kg (according flight data monitoring data) displayed by the FMS. The captain did not notice this difference either. The difference between the takeoff reference speeds, as displayed by the EFB and the FMS, was also not detected by both pilots.

In the Boeing manuals is clearly stated that the takeoff performance calculation shall be made by both pilots, independently from each other, whereafter the results shall be compared to detect gross errors. In this case the captain mentioned aloud to the first officer the takeoff weight to be used. The first officer used this weight to calculate the performance data on his EFB. By telling the first officer what weight to use, the takeoff performance calculation can no longer be classified as an independent process. The safety net to avoid gross calculation errors was therefore lost.

Data comparison

The EFB can only receive limited data from the flight management system (FMS) when using its onboard performance tool. The tool is not capable of sending data, such as the results of the performance calculation, to the FMS. Between the two EFBs, there is a capability to compare information.

The EFB incorporates a weight comparison check between the takeoff weight entered in the onboard performance tool and the gross weight that is calculated by the FMS.

27 The difference of 70,000 kg is 23,4% of the actual TOW.

If these values differ by a predetermined difference, the following caution message will be displayed on the EFB:

> Input weight exceeds tolerance from FMC input weight. Please check.

If the system is unable to make a comparison between the onboard performance tool calculated takeoff weight and FMS gross weight, the message below will be shown on the EFB:

> Unable to verify input weight against FMC weight. Please confirm.

The comparison check on the EFB can only be used if the FMS has been programmed and has calculated the gross weight of the aeroplane. Based on the available flight data, it could not be determined if a warning was generated by the weight comparison check of the EFB and if this check had been performed.

In December 2018, Boeing Commercial Airplane Group, issued a Flight Operations Technical bulletin, titled 'Reducing Takeoff Performance Errors'.[28] The reason for this was to provide techniques for the verification of takeoff performance data to assist in reducing takeoff performance errors. In the bulletin, Boeing recommends a crosscheck technique for five calculated performance parameters:

- N1/EPR/TPR thrust target
- Flap position
- V_1
- V_R
- V_2

The bulletin states that if any differences are seen between the values on the FMC TAKEOFF REF page and the other sources, examine the input data for possible errors. If no errors are found, verify that the FMC values are correct, determine why the difference exists and whether it is acceptable for the flight. If this determination cannot be made, the takeoff performance should be re-calculated.

28 Number 777-18-54.

Under time pressure, incorrect data was supplied to the pilots. Neither the airline's loading procedures nor the cross check of data by the pilots did prevent the use of the wrong data for the takeoff performance calculation.

The interaction between human performance, the cross check of data by the pilots, the airline's loading procedures, limited systems integration and operational pressure to meet the planned takeoff time contributed to the erroneous takeoff performance calculation.

2.2.3 The cause of the tailstrike

The takeoff performance calculation resulted in an engine thrust setting which was insufficient for the aeroplane's actual weight.[29] As a result, the aeroplane rotated at a speed below the speed needed for the actual weight. This resulted in the tail strike due to overrotation of the aeroplane due to the increased time from the beginning of the rotation to the actual liftoff of the aeroplane.

The Boeing procedures specify that if a tail strike occurs, without a 'tail strike' caution message being presented on the EICAS, the flight could be continued. However, these procedures had not been incorporated in the airline's procedures. Based on the unusual scraping sound that had been observed by a cabin attendant, the first officer who experienced a bump and an air traffic controller who had observed a possible tail strike, the flight crew treated the event as an actual tail strike. They followed airline's procedures and thus returned to Schiphol.

Analysis of flight data reveals that during rotation, the column deflection increased while the elevator deflection decreased, which indicates that the tail strike protection system was active. It is however possible that the steering commands are increased beyond the capability for the tailstrike protection system to avoid a tailstrike. The DFDR revealed that the tailstrike protection system operated as designed with its maximum input to avoid a tailstrike.

The tailstrike was caused by an overrotation during takeoff, which was the result of a lower than required rotation speed. The reason for this was that the actual takeoff weight was higher than the takeoff weight that had been used for the takeoff performance calculation.

As a consequence, the take off took place with insufficient engine thrust, which was not detected by the crew and not corrected by manually advancing the thrust levers to provide the additional thrust needed.

29 The actual weight was 70.000 kg more than the weight used for the takeoff performance calculation.

2.2.4 The severity of the occurrence

Big picture

Numerous investigations have shown that an incorrect takeoff performance calculation has the following consequences:

- Calculated takeoff speeds become invalid.
- Increased risk of a tail strike during takeoff.
- Reduced margin between the stall speed and the calculated climb out speed after becoming airborne.
- Reduced obstacle clearance after takeoff as the required climb gradient cannot be met.
- Increased risk of a runway overrun in case of an engine failure before V_1.
- Increased risk of not becoming airborne in case of an engine failure at or just after V_1.

In the worst case scenario, a performance miscalculation could lead to a situation where, even without an engine failure, a takeoff is commenced with a too low thrust setting. This could lead to a situation where there is not sufficient runway length available to become airborne.

Present case

Boeing made takeoff performance calculations to reveal the consequences of a potentially rejected takeoff with all engines operative and in case of a continued takeoff with an engine failure.[30]

A rejected takeoff at V_1 with all engines operative

For an all-engine operative rejected takeoff at a V_1 of 152 knots, with the actual thrust and flap setting and no thrust reversers being used, the stopping distance was 10,798 ft. The Accelerate Stop Distance Available (ASDA) for the runway used is 10,732 ft. The actual stopping distance of 10,798 ft would have exceeded the ASDA and a runway overrun would have occurred. For the maximum reverse thrust case, using ASDA, the aeroplane would have remained within the confines of the runway by 169 feet.

A continued takeoff with an engine failure at or just after V_1

If an engine would have failed during or before the first segment of climb[31], reduced thrust on the remaining engine would have resulted in a negative climb gradient. If an engine failed during the second segment of climb[32], reduced thrust on the remaining engine would have resulted in a climb gradient that was less than 1%. The reason for not being able to maintain the minimum climb gradient is that the actual airspeed flown was below the required minimum airspeed for a climb out with one engine failed. If the takeoff would have been continued with an engine failure at or just after V_1, the minimum climb gradient of 3.3% for the standard instrument departure at Schiphol would not have been met.

30 Letter 66-ZB-H200-ASI-19026, 9 March 2018.
31 From V_1, through lift-off, to gear up.
32 From gear up to 400 feet.

The above illustrates the serious risk the aeroplane was exposed to as a result of the executed takeoff based on incorrect takeoff data.[33] It is emphasised that if emergency procedures had been followed, the aeroplane would not have been able to meet the performance criteria for an engine failure at or just after V_1 or an engine failure at or after lift-off.

The use of incorrect data for the takeoff performance calculation led to an incorrect thrust setting resulting in a takeoff being performed without the required safety margins. In case of an engine failure at or just after the V_1 decision speed or at or after liftoff, the aeroplane would not have been able to continue the flight safely.

2.3 Developments in the field of takeoff performance occurrences

2.3.1 Dutch investigations and follow up recommendations

The Dutch Safety Board (DSB) has investigated several takeoff performance related occurrences in the period 2009-2019.[34] In all of these cases, insufficient thrust was used for takeoff. In these cases, the use of incorrect data resulted in inadequate thrust settings and incorrect takeoff reference speeds for the given aeroplane configuration and aerodrome conditions. One of the occurrences investigated concerned an intersection takeoff at Lisbon Airport in December 2015.[35] The pilots noticed that the remaining runway length was less than expected during the takeoff roll, shortly prior to rotation. It seemed that the takeoff performance had been calculated for an incorrect runway/takeoff position combination due to an EFB input error. As a consequence the available runway length was less than required to maintain acceptable safety margins.

In March 2018 the DSB published the report *Insufficient thrust setting for takeoff.* The DSB recommended to EASA:

1. to prioritise the development of specifications and the establishment of requirements for onboard weight and balance systems.
2. to, in cooperation with other regulatory authorities, standardisation bodies, the aviation industry and airline operators, start the development of specifications and the establishment of requirements for Takeoff Performance Monitoring Systems without further delay.

In December 2019, EASA sent a final response to the first recommendation. It mentioned that the European Organization for Civil Aviation Equipment (EUROCAE) working group (WG-88), which includes EASA as a member, has developed a Minimum Operational Performance Standard (MOPS) for On-Board Weight and Balance Systems (OBWBS) on CS-25 large aeroplanes.

33 If the thrust settings values for the engines, as calculated by the EFB, are based on incorrect data, those thrust setting values will result in insufficient engine thrust after being inserted in the FMS.

34 B777-300 (2009), B777-300ER (2013), two B737-800 (2014 and 2015). One incident with a B737-800 (2018) was still under investigation at the time of publication of this report.

35 Dutch Safety Board, *Insufficient thrust setting for take-off,* March 2018.

Onboard weight and balance systems:
An autonomous On-Board Weight and Balance System (OBWBS) provides pilots with the actual weight and balance information (real time). This information may serve as a crosscheck (secondary system) or the source (primary system) or the weight and balance values used in the performance data process.

Source: Dutch Safety Board.[36]

The MOPS, document ED-263, has been issued in June 2019. It defines the minimum specifications to be met for a class II or secondary OBWBS, i.e. an advisory system that displays the measured aeroplane gross weight and the calculated centre of gravity. The displayed information can be used by the flight crew as an independent means to cross check the conventional weight and balance documentation provided to them and used to calculate the takeoff performance parameters, and the data entered in the aeroplane computers. The EUROCAE standard ED-263 is available to support the certification of OBWBS when a (voluntary) application is received from the industry.

Furthermore, Erroneous Takeoff Performance Parameters is recognized and embedded in the Safety Risk Portfolio and integrated in the Safety Risk Management process, where it has already been identified as a priority safety issue. In this context, a Best Intervention Strategy is currently been carried out to identify suitable actions to be undertaken. In February 2020, EASA mentioned that the estimated costs and benefits for the technical solutions of the minimal requirements developed by EUROCAE WG88 on design related solutions to identify the actual aeroplane gross weight and centre of gravity before takeoff are under review for 2020.

In June 2018, EASA sent a final response to the second recommendation. A EUROCAE Working Group (WG-94) was convened in 2012, at the request of, and with the participation of EASA. The aim was to undertake preparatory work to establish the feasibility of the development of EUROCAE standard(s) defining the requirements for a Takeoff Performance Monitoring System (TOPMS). Such a system has to provide a timely alert to flight crew when the achieved takeoff performance is inadequate for the given aeroplane configuration and aerodrome conditions. WG-94 issued their report in February 2015, concluding that the development of standards to define performance requirements and operational conditions for TOPMS is not currently feasible. This was due to a multitude of factors, including the maturity of the technology, a lack of real-time data (e.g. environmental parameters, runway conditions, airport databases, etc.) and/or suitable aeroplane performance models, a lack of consensus in design criteria and testing methods. The Agency found that the overall feasibility of TOPMS has still not been demonstrated, and no specifications could be developed at that stage.

36 Dutch Safety Board, *Insufficient thrust setting for take-off*, March 2018.

Takeoff performance monitoring systems:
An autonomous Take-Off Performance Monitoring System (TOPMS) provides pilots with real-time information and warnings regarding the takeoff performance. It is a last defence barrier protecting against a multitude of takeoff performance related errors.

Source: Dutch Safety Board.[37]

2.3.2 Further actions taken by EASA

EASA issued a Safety Information Bulletin[38] in February 2016 regarding the use of erroneous parameters at takeoff. In this bulletin EASA recommends:

- that operators and approved training organisations consider the risk related to the use of erroneous takeoff parameters,
- that operators and approved training organisations emphasise during initial and recurrent flight crew training the calculation and use of takeoff performance data, and
- operators to define and implement specific flight data monitoring (FDM) events relevant to the monitoring of takeoff performance issues in their FDM programme.

In 2020 the following actions are under review through EASA's Best Intervention Strategy:

- Review technical solutions related to EUROCAE WG 88 (MOPS) and cost benefit;
- Recommendation for technical solutions to capture wrong T/O parameters;
- Recommendation for technical solutions to capture inadequate acceleration versus expected or insufficient runway length.

2.3.3 Other investigations

According to a study by the Australian Transport Safety Bureau[39], due to the immense variations in the mechanisms involved in making takeoff parameter calculation and entry errors, there is no single solution to ensure that such errors are prevented or captured. This study has shown that these types of events occur irrespective of the airline or aeroplane type, and that they can happen to anyone; no-one is immune. While it is likely that these errors will continue to take place, it is therefore urgent that the aviation industry continues to explore solutions to minimise the changes for takeoff performance parameter errors from occurring and to maximise the chance that any errors that do occur are detected and/or do not lead to negative consequences.

A comprehensive list of accidents and (serious) incidents between 1998 and 2018 is given in the paper *Take-off performance incidents: do we need to accept them or can we avoid them?*[40] The list includes only the occurrences, investigated by the state accident investigation agencies. The actual number of incidents is higher, because many of the takeoff performance incidents are investigated by the operator only or remain undetected by the crew or flight data monitoring programmes.

37 Dutch Safety Board, *Insufficient thrust setting for take-off,* March 2018.
38 SIB No.: 2016-02.
39 Australian Transport Safety Bureau, *Take-off performance calculation and entry errors: A global perspective,* Aviation Research and Analysis Report - AR-2009-052, 2011.
40 Martinair, KLM, NLR: ISASI annual seminar, September 2019.

The abovementioned paper, safety information bulletins and investigation reports from different state accident investigation agencies address the risks concerning reduced thrust takeoffs. A review of these reports and the investigations into similar recent occurrences show that the risk of the use of erroneous parameters at takeoff, with serious safety risks as a consequence, still exists in commercial airline operations.

2.3.4 Global developments

Efforts taken by the airline industry, by improving operational procedures, have not eliminated the risk. Next to the already existing operational procedures, it is urgent to fully integrate new systems in the cockpit and flight management systems, which should eliminate the majority of takeoff performance parameter errors from occurring.

Secondly, these systems should maximise the chance for detection of these errors to timely correct dangerous situations from occurring. In 2018 Airbus developed a Takeoff Monitoring (TOM) function on the A380 in 2018, which is now also available on the A350. TOM monitors the acceleration of the aeroplane during the takeoff phase and warns the flight crew if a lower-than-expected acceleration is detected.[41]

In July 2020, Boeing stated that it is actively developing a Takeoff Acceleration/ Performance Monitoring System and that design options are in development and will be evaluated in simulator and airplane flight testing, as part of the development process.
The solutions to reduce the number of takeoff performance occurrences is a combination of operational measures, integrated and new systems in the cockpit and human performance.

Investigation reports into takeoff performance occurrences show that in the past decades the airline industry has made efforts on a global scale to improve the operational procedures to prevent incorrect takeoff thrust settings. However, these efforts have not resulted in a significant reduction of the risk and incidents.

It is urgent to introduce new systems that are fully integrated in the cockpit and among others provide a timely alert to flight crew when the achieved takeoff performance is inadequate for the given aeroplane configuration, actual weight and balance and aerodrome conditions.

41 Airbus, *Takeoff Surveillance & Monitoring Functions, Safety First,* October 2019.

3 CONCLUSIONS

The tailstrike was caused by an overrotation of the aeroplane during the takeoff, which was the result of a lower than required rotation speed. The reason for this was that the actual takeoff weight was higher than the takeoff weight that had been used for the takeoff performance calculation.

As a consequence, the take off took place with insufficient engine thrust, which was not detected by the crew and not corrected by manually advancing the thrust levers to provide the additional thrust needed.

One passenger had not shown up, which resulted in a manual last minute change on the loadsheet. The actual takeoff weight on the loadsheet was amended and written down erroneously. This was not detected and the data was used for the takeoff performance calculation. It could not be determined if a warning was generated by the Electronic Flight Bag, resulting from the difference between the erroneous takeoff weight manually entered and the correct weight calculated by the Flight Management System.

Under time pressure, incorrect data was supplied to the pilots. Neither the airline's loading procedures nor the cross check of data by the pilots did prevent the use of the wrong data for the takeoff performance calculaton.

The interaction between human performance, the cross check of data by the pilots, the airline's loading procedures, limited systems integration and operational pressure to meet the planned takeoff time contributed to the erroneous takeoff performance calculation.

The use of incorrect data for the takeoff performance calculation led to an incorrect thrust setting resulting in a takeoff being performed without the required safety margins. In case of an engine failure at or just after the V_1 decision speed or at or after liftoff, the aeroplane would not have been able to continue the flight safely.

Investigation reports into takeoff performance occurrences show that in the past decades the airline industry has made efforts on a global scale to improve the operational procedures to prevent incorrect takeoff thrust settings. However these efforts have not resulted in a significant reduction of the risk and incidents.

It is urgent to introduce new systems that are fully integrated in the cockpit and among others provide a timely alert to flight crew when the achieved takeoff performance is inadequate for the given aeroplane configuration, actual weight and balance and aerodrome conditions.

4 RECOMMENDATIONS

In March 2018 the Dutch Safety Board published the report *Insufficient thrust setting for takeoff* in which it recommended to EASA to start, in cooperation with other regulatory authorities, standardisation bodies, the aviation industry and airline operators, the development of specifications and the establishment of requirements for Takeoff Performance Monitoring Systems (TOPMS) without further delay. Such a system has to provide a timely alert to flight crew when the achieved takeoff performance is inadequate for the given aeroplane configuration and aerodrome conditions, including the runway length available in case of intersection takeoffs.

At the time of writing this report the overall feasibility of TOPMS has still not been demonstrated because of the complexity of such a system. As a result, no technical specifications or guidance materials to define the operational performance of such a system have been drafted. At the same time, takeoff performance occurrences continue to occur, and therefore the development of technological solutions is still urgent. Systems detecting gross input errors and deviations in parameter settings or comparing predicted and actual aeroplane acceleration during the takeoff run are systems that are considered feasible as a first step towards a more complex TOPMS.

Reduced thrust takeoffs are commonly used as a cost reduction measure. However, performing reduced thrust takeoffs introduces safety risks, such as the risk of input of erroneous takeoff parameters into the Electronic Flight Bag and/or Flight Management System as well as a reduction of the takeoff performance safety margins. The erroneous data input may lead to calculated takeoff speeds and thrust settings being lower than required, causing a flight safety hazard, because the required takeoff roll increases. In case of only minimal changes in takeoff parameters, the resulting additional cost reduction will probably also be marginal. However, changing the input data introduces the risk of erroneous entries, especially when a change is introduced last minute. Currently, there is insufficient insight in the relation between the actual cost reduction on one hand and the increase in safety risk with respect to erroneous data entry on the other hand. Also, there is no common airline policy or procedure regarding reduced thrust takeoffs and the entry of takeoff performance data. The Dutch Safety Board is of the opinion that operators need to consider the benefits of reduced thrust takeoffs against the possible safety risks, like reduced safety margins in case of an engine failure after the decision speed V_1.

The Dutch Safety Board therefore issues the following recommendations:

To European Union Aviation Safety Agency and the Federal Aviation Administration:

To take the initiative in the development of specifications and, subsequently, develop requirements for an independent onboard system that detects gross input errors in the process of takeoff performance calculations and/or alerts the flight crew during takeoff of abnormal low accelerations for the actual aeroplane configuration as well as insufficient runway length available in case of intersection takeoffs. Take this initiative in close consult with the aviation industry, including manufacturers of commercial jetliners amongst which in any case The Boeing Company.

To International Air Transport Association:

To develop a standard policy for airlines with regard to procedures for reduced thrust takeoffs, including a risk analysis addressing cost reductions versus introduced safety risks.

To The Boeing Company:

For the existing and future commercial aeroplanes, to research on and develop an independent onboard system that detects gross input errors in the process of takeoff performance calculations and/or alerts the flight crew during takeoff of abnormal low accelerations for the actual aeroplane configuration as well as insufficient runway length available in case of intersection takeoffs.

To International Civil Aviation Organization:

To note the conclusions of this report and introduce provisions addressing an independent onboard system that detects gross input errors in the process of takeoff performance calculations and/or alerts the flight crew during takeoff of abnormal low accelerations for the actual aeroplane configuration as well as insufficient runway length available in case of intersection takeoffs.

APPENDIX A

COMMENTS ON DRAFT REPORT

A draft version of this report was submitted to the parties directly involved, in accordance with the Dutch Safety Board Kingdom Act. These parties were requested to check the report for any factual inaccuracies and ambiguities.

The draft report was submitted to the following parties:

- Aircraft Accident Investigation Bureau, India
- The Boeing Company
- European Union Aviation Safety Agency
- Flight crew members
- Human Environment and Transport Inspectorate
- KLM Royal Dutch Airlines
- Ministry of Infrastructure and Water Management
- National Transportation Safety Board, USA

The Board has taken note of the responses received. The responses and explanations are listed in a table which is available on the website of the Dutch Safety Board: https://www.onderzoeksraad.nl/en/.

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