DUTCH
SAFETY BOARD

Insufficient thrust setting for take-off

Insufficient thrust setting for take-off

The Hague, March 2018

The Dutch Safety Board

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This report is published in the English and Dutch languages. If there is a difference in interpretation between the English and Dutch versions, the English text will prevail.

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GLOSSARY

ACI	Airports Council International
ACMS	Aircraft Condition Monitoring System
ARMS	Aviation Risk Management Solutions
ASDA	Accelerate-Stop Distance Available: The length of the take-off run available plus the length of the stopway, if provided. Usually, this is the runway length available from the beginning of the runway or from a certain intersection or position (see figure 1).
ASDR	Accelerate-Stop Distance Required: see also ASDA.
ASR	Air Safety Report
Assumed temperature thrust reduction method	A way of reducing the take-off thrust to the minimum required for a safe take-off, thereby conserving engine life and hence reducing the chances of an engine failure
ATC	Air Traffic Control
ATIS	Automatic Terminal Information System
Balanced field take-off	A condition where the ASDR is equal to the TODR for the aircraft weight, engine thrust, aircraft configuration, runway and wind conditions
Bugcard	Take-Off or Landing Data Card
CDU	Control Display Unit (displays FMC data and messages)
CG	Centre of Gravity
Clearway	A defined rectangular area on the ground or water under the control of the appropriate authority, selected or prepared as a suitable area over which an aeroplane may make a portion of its initial climb to a specified height
EASA	European Aviation Safety Agency
EFB	Electronic Flight Bag. This is a tablet style computer which contains information that the flight crew uses during flight such as manuals and navigation charts. The EFB is also used for the weight & balance and the performance calculation
EUROCAE	European Organisation for Civil Aviation Equipment
FCIS	Flight Crew Information Sheet
FCOM (1 & 2)	Flight Crew Operations Manual (Volume 1 and 2). Is part of the Aircraft Operations Manual – Part B. Contains aircraft type specific information, related to the aircraft operation.
FCTM	Flight Crew Training Manual, is part of the Aircraft Operations Manual – Part B. Contains aircraft type specific information, related to the aircraft operation.

FDM	Flight Data Monitoring
FMC	Flight Management Computer (Component of the FMS)
FMS	Flight Management System
GPIAA	Portuguese Aviation Prevention and Investigation Department
GPS	Global Positioning System
GW	Gross Weight, the total mass of the aircraft
hPa	Hectopascal, unit of air pressure (1 hPa = 1 millibar)
kg	kilogram(s)
kt	knot(s)
Lido	A Lufthansa systems company that provides software solutions for airline operators, such as digital navigation charts and performance calculation software
LTS	Load and Trim Sheet
MAB	EFB weight and balance
MOPS	Minimum Operational Performance Standard
OBWBS	On-Board Weight and Balance Systems
OFP	Operational Flight Plan
OM-A[1]	Operations Manual - Part A
OPT	Onboard Performance Tool
PIA	Preliminary Impact Assessment
QNH	The reference atmospheric pressure adjusted to sea level
S&QA	Safety & Quality Assurance department of the operator
S3	Intersection S3 of runway 05 at Groningen Airport Eelde
SMS	Safety Management System
SOP	Standard Operating Procedures
Stopway	A paved area beyond the runway which can be used for deceleration in the case of a rejected take-off.
t	Tonne(s), 1 tonne = 1000 kg
TL-tables	Take-off and Landing performance tables
TODA	Take-Off Distance Available: The length of the take-off run available plus the length of the clearway, if provided (see figure 1).
TODR	Take-Off Distance Required: see also TODA
TOGA	Take-Off and Go Around
TOM	Take-Off Monitoring

1 The Operations Manual – Part A contains operational information that is not aircraft type specific.

TOS	Take-Off Securing
TOW	Take-Off Weight
TOPM or TOPMS	Take-Off Performance Monitoring System
TORA	Take-Off Run Available: The length of runway declared available and suitable for the ground run of an aeroplane taking off (see figure 1).
TORR	Take-Off Run Required: see also TORA
V_1	Take-off decision speed
V_r	Rotation speed
V_2	Take-off safety speed
ZFW	Zero Fuel Weight

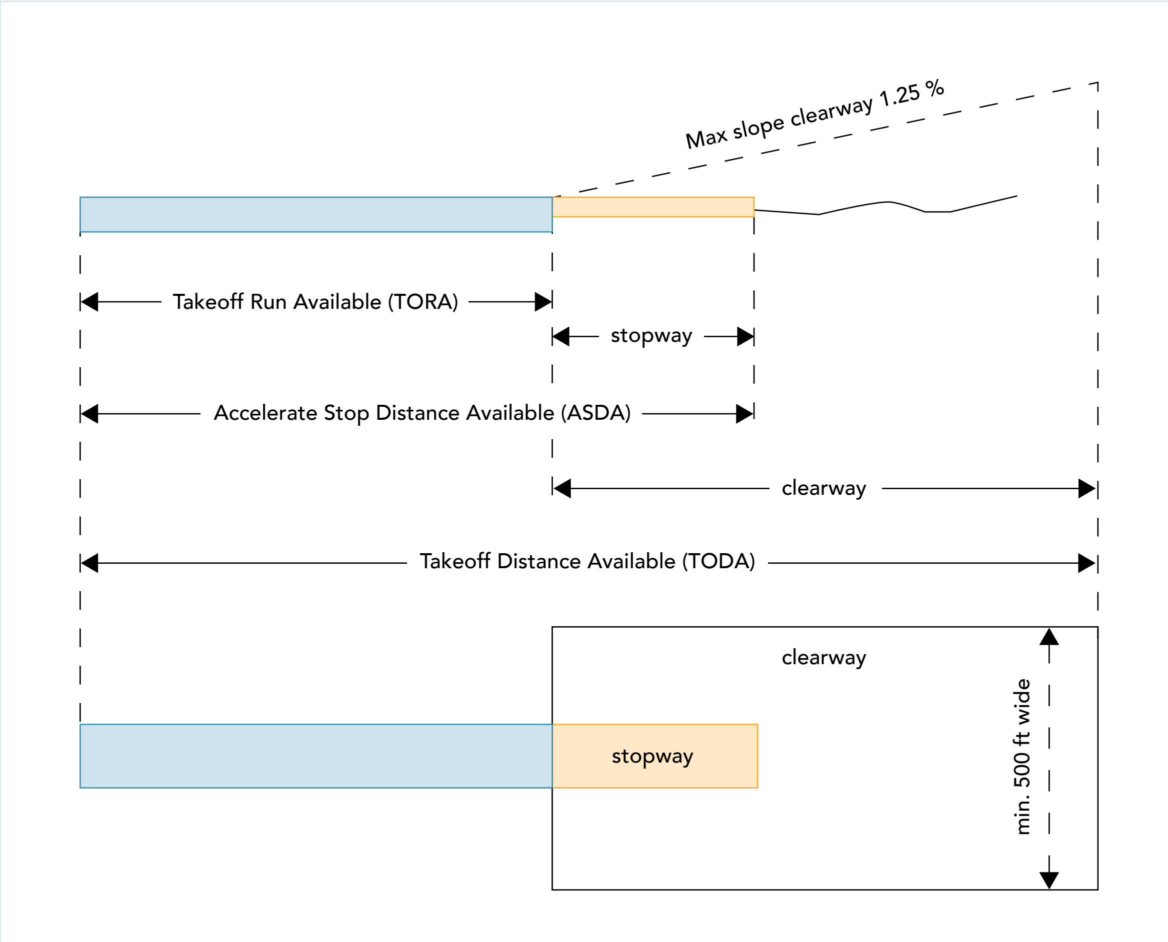

Figure 1: Illustration of TORA, ASDA, TODA, stopway and clearway.

GENERAL INFORMATION

Occurrence 1	
Reference occurrence:	LV2014102
Classification:	Serious incident
Date, time of occurrence:	18 September 2014, 15:15 hours local time (UTC+2)
Location of occurrence:	Groningen Airport Eelde, EHGG
Departure station:	Groningen Airport Eelde, EHGG
Destination station:	Rotterdam The Hague Airport, EHRD
Aircraft model:	Boeing 737-800
Type of aircraft:	Twin engine passenger aircraft
Type of flight:	Carrier / commercial
Phase of flight:	Take-off
Damage to aircraft:	None
Number of crew:	2 cockpit, 4 cabin
Number of passengers:	173
Injuries:	0
Other damage:	None
Lighting conditions:	Daylight

Table 1: Summary of factual information Groningen incident.

Occurrence 2	
Reference occurrence:	LV2015107
Classification:	Serious incident
Date, time of occurrence:	3 December 2015, 19:27 hours local time (UTC)
Location of occurrence:	Lisbon Airport, LPPT
Departure station:	Lisbon Airport, LPPT
Destination station:	Amsterdam Airport Schiphol, EHAM
Aircraft model:	Boeing 737-800
Type of aircraft:	Twin engine passenger aircraft
Type of flight:	Carrier / commercial
Phase of flight:	Take-off
Damage to aircraft:	None
Number of crew:	2 cockpit, 4 cabin
Number of passengers:	175
Injuries:	0
Other damage:	None
Lighting conditions:	Darkness

Table 2: Summary of factual information Lisbon incident.

SUMMARY

This report analyses two serious incidents involving an insufficient thrust setting for take-off that occurred with the same operator. Besides the insufficient thrust setting, the calculated take-off speeds were invalid. In both incidents the required safety margins for take-off performance were not met, increasing the risk of a runway overrun, tail strike and a collision with an obstacle after departure. During the first serious incident (2014) the operator made use of manual performance calculations, whilst the second serious incident (2015) occurred after the operator had introduced digital performance calculations on an Electronic Flight Bag (EFB). These incidents are not unique. Worldwide, numerous incidents with erroneous take-off parameters occurred over the years.

On September 18, 2014 a Boeing 737-800 started its take-off at Groningen Airport Eelde for a flight to Rotterdam The Hague Airport. During the take-off roll the pilots became aware that the acceleration was less than expected. The take-off was continued. The take-off weight used for the performance calculation was 10 tonnes too low due to a miscalculation of the take-off weight on the take-off data card (bugcard) by the flight crew. As a consequence the selected take-off thrust was lower than required. Approximately 60 metres before the end of the runway the aircraft became airborne.

On December 3, 2015, a Boeing 737-800 departed from Lisbon Airport to Amsterdam Airport Schiphol. The pilots noticed that the remaining runway length was less than expected during the take-off roll, shortly prior to rotation. The take-off was continued. Approximately 430 metres before the end of the runway the aircraft became airborne. The take-off performance in Lisbon was calculated for an incorrect runway/take-off position combination due to an EFB input error, which was possible due to unclear naming of take-off positions at Lisbon Airport. As a consequence the available runway length was 1,120 metres less than calculated.

A common factor in both incidents was that the errors could propagate, because there were no adequate crosschecks in place to detect the specific errors made by the flight crew. A crosscheck detecting the erroneous take-off weight on the bugcard was lacking in the Groningen incident. A crosscheck detecting that both pilots were making the same runway selection error was lacking in the Lisbon incident. Another common factor in both incidents was that the flight crew did not select additional thrust after realizing the take-off roll was unusually long.

The operator stated in an internal investigation report into data entry errors (completed on October 1st, 2014) that the existing crosschecking policy could be inadequate. However, the report did not formulate recommendations to include the bugcard in a crosscheck. The operator's manual load and trim procedure, including the use of the bugcard, was not reviewed after the Groningen incident, although, the manual load and trim procedure is still in place as a back-up in case of an EFB failure.

When the operator carried out the risk assessment for the introduction of the EFB, they did not perform a risk assessment for the software that would be installed on the EFB because it was not yet available at the time the risk assessment was performed. Besides that, the operator did not perform an internal investigation into the causes of data entry errors on the EFB when it became apparent from continuously monitoring that data entry errors are regularly made in the operation.

The development of new and independent monitoring systems, aimed to provide flight crews with a timely warning that the required take-off performance cannot be achieved, is slow. EASA has not classified the development of the regulatory framework of these systems as a high priority due to a low amount of fatalities in take-off performance related incidents (3 fatal accidents in 16 years). The Dutch Safety Board is of the opinion that such systems have a high likelihood of preventing serious take-off performance incidents. The development of specifications and the establishment of requirements for Onboard Weight and Balance Systems should be prioritized and the development of specifications and the establishment of requirements for Take-off Performance Monitoring Systems should be started without further delay.

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Inleiding

In dit rapport worden twee ernstige incidenten bij dezelfde luchtvaartmaatschappij geanalyseerd. Bij beide incidenten was bij de start onvoldoende vermogen van de motoren ingesteld. Dat kwam doordat er verkeerde gegevens waren gebruikt voor het berekenen van het te selecteren motorvermogen. Doordat deze verkeerde gegevens ook werden gebruikt om de startsnelheden te berekenen, waren ook de startsnelheden niet correct. Bij beide incidenten werd daardoor niet voldaan aan de veiligheidsmarges die zijn gesteld aan startprestaties voor verkeersvliegtuigen. Het te lage motorvermogen had in beide gevallen tot gevolg dat de startrol langer was dan gebruikelijk.

Het is gebruikelijk dat verkeersvliegtuigen tijdens de start geen gebruik maken van het volledige vermogen van de vliegtuigmotoren. De bemanning berekent het minimale vermogen dat nodig is voor een veilige start. Dit heeft voordelen, zoals een grotere betrouwbaarheid en lagere onderhoudskosten van de motoren. Deze prestatieberekeningen zijn altijd gebaseerd op de mogelijkheid van een motorstoring op het meest kritieke punt tijdens de startprocedure. In het geval van een storing van één van de motoren moet het vliegtuig ofwel in staat zijn om de start veilig af te breken, of de start voort te zetten binnen de resterende lengte van de startbaan.

Incidenten waarbij er sprake is van onvoldoende motorvermogen tijdens de start komen in de luchtvaart wereldwijd regelmatig voor. Verschillende keren leidde dit tot ongevallen met catastrofale gevolgen. De meerderheid van deze voorvallen werd veroorzaakt door fouten in de berekening, of door fouten in de gegevensinvoer voor het berekenen van de startparameters.

Onjuistheden in de berekeningen van startprestaties hebben tot gevolg dat de beschikbare veiligheidsmarges worden gereduceerd of overschreden. Wanneer de fout in de berekening van de startprestaties ernstig is, kan dit leiden tot een situatie waarin, zelfs zonder motorstoring, er niet voldoende startbaanlengte beschikbaar is voor de start. Een startprestatiefout heeft invloed op de berekende startsnelheden, die daardoor niet meer kloppen. Als gevolg hiervan is de werkelijke snelheid waarmee de start veilig kan worden afgebroken of moet worden voortgezet op de werkende motor(en) onbekend. Er is dan een fase tijdens de start waarbij, in het geval van een motorstoring, noch voldoende startbaanlengte overblijft om het vliegtuig tot een veilige stop te brengen, noch voldoende startbaanlengte overblijft om veilig de start voort te zetten en veilig het luchtruim te kiezen. Een ernstige fout in de startprestaties vergroot de risico's op een *runway overrun*; een *tail strike* waarbij de achterkant van een vliegtuig de startbaan raakt door een te grote invalshoek bij het opstijgen; een botsing met een obstakel; of het verliezen van lift (stall) na vertrek.

Bij de twee onderzochte ernstige incidenten werden de startprestaties op een verschillende manier bepaald. Tijdens het eerste voorval (in 2014) werden de startprestaties door de cockpitbemanning handmatig bepaald. Deze methode bestond uit het invullen van het load en trim sheet (LTS), waarbij de cockpitbemanning onder andere handmatig de startgewichten berekende. Vervolgens nam de bemanning de gewichten en andere gegevens over op de *take-off* and *landing data card* (*bugcard*). De bemanning bepaalde tenslotte de startprestaties met behulp van de op de bugcard verzamelde gegevens en de *take-off and landing performance tabellen* (*TL-tabellen*).

Bij het tweede voorval (in 2015) werd de handmatige methode niet meer standaard toegepast door de luchtvaartmaatschappij. De cockpitbemanning maakte gebruik van digitale startprestatieberekeningen op een Electronic Flight Bag (EFB). De EFB is een tabletachtige computer die informatie bevat die de cockpitbemanning tijdens de vlucht gebruikt, zoals handleidingen en navigatiekaarten. De EFB kan ook gebruikt worden voor het bepalen van de gewichten van het vliegtuig en de berekening van de startprestaties.

Toedracht

Het eerste incident vond plaats op Groningen Airport Eelde op 18 september 2014. Een Boeing 737-800 vertrok om 15:07 uur voor een vlucht naar Rotterdam The Hague Airport. Tijdens de startrol merkten de piloten dat de versnelling van het vliegtuig minder was dan verwacht. De start werd doorgezet en het vliegtuig had bijna de hele startbaan nodig voor de start. De rest van de vlucht verliep zonder problemen. Het vliegtuig landde om 15:53 uur in Rotterdam. Er was geen schade aan het vliegtuig en de bemanning en passagiers bleven ongedeerd.

Het startgewicht dat de cockpitbemanning gebruikte voor de berekening van de startprestaties was 10.000 kg te laag. Dit kwam doordat de cockpitbemanning een verkeerde berekening van het startgewicht op de bugcard had uitgevoerd. Hierdoor waren de startprestaties die de bemanning bepaalde aan de hand van de TL-tabellen niet correct, waardoor het geselecteerde vermogen lager was dan vereist. Het vliegtuig kwam ongeveer 60 meter voor het einde van de startbaan los van de grond.

Het tweede incident vond plaats op de luchthaven van Lissabon, Portugal, op 3 december 2015. Een Boeing 737-800 vertrok om 19:27 uur lokale tijd naar Amsterdam Airport Schiphol. Tijdens de start, merkten de piloten kort voor de rotatie dat de resterende baanlengte op dat punt minder was dan verwacht. Het vliegtuig kwam ongeveer 430 meter voor het einde van de startbaan los van de grond. De rest van de vlucht verliep zonder problemen. Er was geen schade aan het vliegtuig en de bemanning en passagiers bleven ongedeerd.

Uit het onderzoek blijkt dat de startprestaties in Lissabon op de EFB waren berekend voor een andere startbaan dan vanwaar het vliegtuig vertrok. De cockpitbemanning had een onjuiste combinatie van oplijningspositie en startbaan geselecteerd. De onduidelijke

en niet-unieke benaming van oplijningsposities op de luchthaven van Lissabon heeft hier mogelijk aan bijgedragen. Het gevolg van de selectiefout was dat de startprestaties werden berekend op basis van een landingsbaan die 1120 meter langer was. De berekeningen resulteerden in onvoldoende motorvermogen om de vereiste veiligheidsmarges te halen.
Bij beide voorvallen selecteerden de cockpitbemanningen geen extra motorvermogen nadat zij zich realiseerde dat de startrol ongewoon lang was.

Crosschecks
Een gemeenschappelijke factor bij beide voorvallen is dat fouten niet werden opgemerkt, omdat er geen adequate *crosschecks* waren om de specifieke fouten van de cockpitbemanning op te sporen. Crosschecken is een manier om fouten in de gegevensinvoer of berekeningen te voorkomen of te detecteren. Bij crosschecken wordt de validiteit van een getal, bijvoorbeeld een berekend gewicht of een berekende startprestatie, gecontroleerd door het te vergelijken met de waarde uit een andere beschikbare bron. Een andere manier om een crosscheck uit te voeren is door twee leden van de cockpitbemanning onafhankelijk een berekening te laten uitvoeren, en de resultaten achteraf met elkaar te vergelijken. Crosschecks zijn vastgelegd in de *Flight Crew Operations Manual* (*FCOM, bron: Boeing*) en zijn onderdeel van trainings-programma's voor de cockpitbemanningen.

Bij het Groningen-incident ontbrak een crosscheck die het foutieve startgewicht op de *bugcard* detecteerde. Bij het incident in Lissabon ontbrak een crosscheck die kon identificeren dat beide piloten dezelfde selectiefout hadden gemaakt op de EFB.

Risicomanagement door de luchtvaartmaatschappij
Toen de luchtvaartmaatschappij in 2013 een risico-assessment voor het invoeren van de EFB uitvoerde, is er geen risicobeoordeling uitgevoerd voor de software die op de EFB zou worden geïnstalleerd, omdat deze nog niet beschikbaar was op dat moment.

De luchtvaartmaatschappij vermeldde in een intern onderzoeksrapport (voltooid op 1 oktober 2014) dat het bestaande crosschecking-beleid ontoereikend zou kunnen zijn om fouten bij het invoeren van gegevens (zogenaamde *data-entry errors*) te ontdekken. Het rapport formuleerde echter geen aanbevelingen om de bugcard in een crosscheck op te nemen. De handmatige procedure van de luchtvaartmaatschappij voor het bepalen van de startprestaties, inclusief het gebruik van de *bugcard*, werd niet onderzocht na het incident in Groningen, hoewel deze procedure nog steeds in gebruik is als back-up in het geval van een EFB-storing.

Toen het tweede voorval plaatsvond was de luchtvaartmaatschappij door continu monitoren op de hoogte dat dat er regelmatig fouten in de gegevensinvoer worden gemaakt tijdens de operatie. Toch heeft de luchtvaartmaatschappij geen intern onderzoek uitgevoerd naar de oorzaken van fouten bij het invoeren van gegevens op de EFB.

Op basis van deze bevindingen concludeert de Onderzoeksraad voor Veiligheid dat het beleid van de luchtvaartmaatschappij voor de beheersing van de risico's met betrekking tot het bepalen van de startprestaties te reactief is gebleken. Het beleid zou meer proactief moeten zijn, in overeenstemming met de uitgangspunten van het veiligheidsmanagementsysteem (VMS). Daarbij zouden actief mitigerende maatregelen moeten worden geïdentificeerd en vervolgens worden ingevoerd.

Automatisering

De Onderzoeksraad voor Veiligheid heeft ook gekeken naar verdere systeemautomatisering als mogelijke barrière voor incidenten waarbij onvoldoende vermogen is geselecteerd voor de start door fouten in de berekening of de gegevensinvoer. Nieuwe en onafhankelijke monitoringsystemen, zoals *Onboard weight and balance systems* (*OBWBS*) en *Take-Off Performance Monitoring Systems* (*TOPMS*) zijn in ontwikkeling met als doel om cockpitbemanningen tijdig te waarschuwen als de berekende startprestaties niet kloppen.

Een *OBWBS* is een gewicht- en balanscontrolesysteem aan boord van het vliegtuig, dat piloten actuele informatie geeft over gewicht en zwaartepunt van het vliegtuig (real-time). Deze informatie kan dienen als crosscheck (secundair systeem) of als de primaire bron (primair systeem) voor de gewichts- en zwaartepuntswaarden die worden gebruikt voor het bepalen van de startprestaties.

Een *TOPMS* of *TOPM* is een autonoom controlesysteem voor startprestaties, dat piloten real-time informatie en waarschuwingen geeft met betrekking tot de startprestaties. Het is een barrière die bescherming biedt tegen een groot aantal fouten in het bepalen van de startprestaties.

Hoewel bovengenoemde systemen veelbelovend zijn, verloopt de ontwikkeling van deze systemen door de industrie traag. Ook heeft de European Aviation Safety Agency (EASA) het ontwikkelen van het regelgevingskader van deze systemen niet als hoge prioriteit geclassificeerd mede doordat het aantal dodelijke slachtoffers in aan startprestaties gerelateerde voorvallen (3 fatale ongevallen in 16 jaar) gering is ten opzichte van ander typen voorvallen. De Onderzoeksraad voor Veiligheid is echter van mening dat deze systemen grote potentie hebben om dergelijke in potentie ernstige voorvallen te voorkomen.

Naast automatisering kan EASA op de kortere termijn preventieve maatregelen nemen die zich richten op richtlijnen en regelgeving op het gebied van EFB-ergonomie, en op procedures voor het gebruik van EFB. Daarnaast kunnen luchtvaartmaatschappijen actief *best practices* delen op het gebied van *weight and balance* en *performance procedures*, omdat startprestatie-gerelateerde voorvallen voorkomen bij diverse types vliegtuigen en vluchtuitvoeringen.

Aanbevelingen

EASA wordt aanbevolen:

1. Om prioriteit te geven aan de ontwikkeling van specificaties en het vaststellen van eisen voor *Onboard weight and balance systems* (RMT.0116).
2. Om onverwijld te starten met de ontwikkeling van specificaties en het vaststellen van eisen voor *Take-Off Performance Monitoring Systems* en daarbij samen te werken met andere regelgevende instanties, standaardisatie-instituten, luchtvaartindustrie en luchtvaartmaatschappijen.

De luchtvaartmaatschappij wordt aanbevolen:

3. Om periodieke risico-assessments uit te voeren en mitigerende maatregelen te nemen op de geïdentificeerde risico's met betrekking tot het gehele vluchtvoorbereidingsproces. Deze periodieke risico-assessments moeten in ieder geval het volgende omvatten, maar zijn hier niet toe beperkt:

   - Handmatige *weight and balance* en *performance procedures;*
   - *Take-off and landing data card* (*bugcard*);
   - EFB (hardware, software, procedures en alternatieven);
   - Het afwegen van de risico's die ontstaan door het reduceren van het motorvermogen bij de start, tegen de financiële voordelen die dit oplevert.

4. Om cockpitbemanningen simulatortraining te geven waarbij uitzonderlijke situaties getraind worden die vereisen dat de crew extra motorvermogen selecteert tijdens de startrol.

Het management van de luchthaven van Lissabon wordt aanbevolen:

5. Om de naamgeving van de oplijningsposities aan te passen, in overeenstemming met de richtlijnen van de Airports Council International.

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1 INTRODUCTION

1.1 Two incidents

On September 18, 2014 a take-off incident with insufficient thrust occurred with a Boeing 737-800 at Groningen Airport Eelde in The Netherlands using intersection S3 of runway 05. Another take-off incident with the same operator occurred using position 3 of runway 21 at Lisbon Airport in Portugal on December 3, 2015. The Dutch Safety Board (DSB) was investigating the Groningen incident when the Lisbon incident occurred. The Portuguese Safety Investigation Authority (GPIAA) delegated the investigation of the Lisbon incident to the DSB. As both incidents show analogies, namely insufficient thrust selection and inadequate crosschecking procedures, the investigation of these incidents is combined in this report.

Crosschecking
Crosschecking is a safeguard to prevent and detect data entry or handling errors. Crosschecking can be conducted in several manners. It can be accomplished by checking the validity of a figure by comparing that figure with other available sources. Crosschecking can also be accomplished by having two flight crew members independently performing a calculation and comparing results afterwards.

A major difference between the two incidents was the phase of introduction of the Electronic Flight Bag (EFB). Around the time of the Groningen incident the operator was in the process of implementing the Electronic Flight Bag (EFB) and not all aircraft were equipped with EFBs (two EFBs are mounted in an aircraft). An EFB is a tablet style computer that is used for, amongst others, the load and balance calculation and the performance calculation. During the Groningen incident the EFB was not yet used for load and balance and performance calculations. Whereas during the Lisbon incident, the EFB was also in operational use for load and balance and performance calculations. The EFB type used by the involved operator is the NavAero T-Bag C2.

1.2 Incidents with erroneous take-off parameters

The investigated incidents are not unique. Worldwide, numerous incidents with erroneous take-off parameters occurred[2] over the years. Several safety boards worldwide investigated this type of occurrences, for instance NTSB (USA), BEA (France),

2 See Appendix F: List of relevant safety studies.

AAIB (Denmark), TSB (Canada) and TAIC (New Zealand). The Dutch Safety Board also investigated this type of incident[3]. The European Aviation Safety Agency (EASA) received 8 safety recommendations from 7 reports on this topic in 1999-2015. EASA published a Safety Information Bulletin on this topic in 2016.[4] The need Safety Information Bulletin[5] was based on a review of 9 incidents and 23 accidents that occurred worldwide in the period 1999-2015. Three of these accidents were fatal.

It is common in the operation of large civil aircraft to not make use of the full rated thrust of the aircraft its engines. Flight crews calculate the minimum amount of thrust required for a safe take-off. This may provide benefits in terms of engine reliability and maintenance costs of the engine. There are two methods of reducing take-off thrust:

- The thrust derate method consists of reducing the take-off thrust by a prespecified percentage of the maximum take-off thrust. The minimum control speeds[6] are adjusted for the derated amount of thrust when using the thrust derate method.
- The assumed temperature thrust reduction method consists of programming a higher than actual Outside Air Temperature (OAT) into the Flight Management Computer (FMC) in order to reduce the amount of thrust generated by the engine. The minimum control speeds remain based on the full rated thrust when using the assumed temperature thrust reduction method. The assumed temperature method can also be used in combination with the thrust derate method. When the combined method is used, minimum control speeds are based on the selected thrust derate.

Performance calculations are always based on the possibility of an engine failure at the most critical point in take-off. In case of an engine failure the aircraft should either be able to safely abort the take-off or continue and become airborne within the remaining runway length. The decision speed by which any action to reject a takeoff must be made is specified as V_1. Above V_1, the take-off must be continued unless there is reason to believe that the aircraft will not fly. An engine failure identified not later than V_1 should always result in a rejected take-off.

During a standard take-off (without engine failure) there is excess runway length remaining at lift-off due to various safety margins. These margins are a result of the following factors:

- The calculated take-off distances and environmental conditions are incremented with safety factors to allow for deviations in the actual conditions.
- The performance calculation takes into account a possible engine failure.
- In case of a long runway, the runway length is often longer than required for take-off with a maximum reduced thrust setting.

3 Dutch Safety Board, *Take-off with insufficient engine thrust, Boeing 777-300ER*, Amsterdam Airport Schiphol, 7 July 2013, published in Quarterly Aviation Report, Q1 2016.
4 EASA Safety Information Bulletin; Operations, SIB No. 2016-02, 16 February 2016.
5 See also paragraph 2.6.1.
6 Minimum control speeds refer to the controllability of the aircraft in case of an engine failure. Separate speeds exist for on the ground and in the air. If the speed is below the minimum control speed when an engine failure occurs, control difficulties will be encountered.

Furthermore, extra thrust is available in case of an assumed temperature thrust reduction method take-off. This can be achieved by advancing the throttle levers to the full forward position during the take-off roll. Because the minimum control speeds are based on full take-off thrust or the selected take-off derate when using the assumed temperature thrust reduction method, the controllability of the aircraft will be assured in case of an engine failure after increasing thrust.

A performance error reduces the available safety margins and can have the following consequences:

- Relevant take-off speeds become invalid. As a consequence the calculated V_1 cannot be used for the decision to abort or continue the take-off. The actual speed at which the take-off can be safely aborted or continued on the operative engine is unknown.
- There is a phase during the take-off where, in case of an engine failure, neither enough runway length is remaining to bring the aircraft to a safe stop, nor enough runway length is remaining to safely continue the take-off. An engine failure during this phase would most likely cause a runway overrun (runway excursion).
- Increased risk of tail strike during take-off.
- Reduced margin between the stall speed and the actual speed after becoming airborne.
- Reduced obstacle clearance after takeoff as the expected climb gradient cannot be met.

When the performance miscalculation is severe enough it could lead to a situation where, even without an engine failure, there is not sufficient runway length available for take-off.

The various reports used in this investigation, see the references in Appendix F, show that similar take-off incidents and accidents have occurred worldwide, several with catastrophic results. Most of these occurrences were caused by calculation or data entry errors. The DSB has investigated a similar performance incident before in 2013[7]. This incident occurred on a Boeing 777 aircraft.

The focus of this report is on the cause and propagation of the performance related errors and the limitations of the current crosschecking procedure. The investigation also looked into further system automation as possible barrier against performance related take-off incidents.

7 *Take-off with insufficient engine thrust, Boeing 777-300ER, Amsterdam Airport Schiphol*, 7 July 2013, published in the Dutch Safety Board's first Quarterly report of 2016.

2 FACTUAL INFORMATION

2.1 Introduction

This chapter starts with the description of the factual information of both incidents. It then provides background information regarding the procedures used by the flight crews in both incidents. In order to place the performance related take-off incidents in a broader perspective, a review of several automated systems is given and the role of EASA in preventing performance related take-off incidents is described.

Flight data for the investigation is based on Aircraft Condition Monitoring System (ACMS) data and interviews only, since both the Flight Data Recorder (FDR) and Cockpit Voice Recorder (CVR) data were overwritten as the incidents were only reported to the Dutch Safety Board several days after the incidents occurred. By this time the data on the FDR and CVR were overwritten.

2.2 Groningen incident

2.2.1 General information

The flight crew was operating on a scheduled three sector passenger service, from Amsterdam Airport Schiphol (Schiphol) via Kos Airport Hippocrates (Kos) and Groningen Airport Eelde to Rotterdam The Hague Airport (Rotterdam). The flight crew checked in at Schiphol at 05:10[8]. The flight crew received the briefing package before departure of the first leg, including the Operational Flight Plans (OFP) and the Load and Trim Sheets (LTS) for all flight sectors. The briefing package contained all planned flight data, valid at the time of printing.

The captain was the pilot flying on the sector from Schiphol to Kos. The first officer was pilot flying from Kos to Groningen and onwards to Rotterdam. The first two sectors were uneventful according to both pilots. The aircraft arrived twelve minutes ahead of schedule in Groningen at 14:28 (on blocks time).

2.2.2 Flight preparation in Groningen

Load and Balance calculation

During the flight preparation the captain completed the weight calculations on the LTS and determined the Zero Fuel Weight[9] (ZFW) and the Take-Off Weight (TOW).

8 All times in this report are local times unless otherwise specified, local time in Groningen was UTC + 2 hr.
9 The operator uses the term Weight and Mass indiscriminately through their manuals. As the Boeing source manuals use the term weight, this term has been used in this report.

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The TOW was 62,9 t. The first officer crosschecked the weight calculations on the LTS (Appendix A, Figure 1). As the passenger distribution information was not available, the pilots had to postpone the Centre of Gravity (CG) determination until the receipt of the Passenger Distribution Card from the purser, which was received approximately five minutes prior to push back. The first officer determined the CG by completing the graph on the LTS.

Take-off or landing data card
All relevant take-off or landing data is gathered on the take-off or landing data card (also known as 'bugcard', see Appendix A, Figure 2). The bugcard is designed to be used as a reference card for the take-off or landing phase of flight. The first officer copied the ZFW from the LTS onto the bugcard. The first officer made a separate calculation of the TOW on the bugcard, by adding the take-off fuel weight of 4.0 tonnes (t) to the ZFW of 58.9 t. The resulting TOW on the bugcard was erroneously calculated to be 52.9 t. The actual take-off weight, as calculated on the LTS, was 62,9 t.

Take-off weight as calculated on the LTS	Take-off weight as calculated on the bugcard
62,9 t	52, 9 t

Table 3: The discrepancy in calculated take-off weights.

Performance Calculation
The required thrust setting for take-off was determined by using the performance charts (TL-tables, see Appendix A, Figure 3 and Appendix A, Figure 4) from the Performance Manual.

The pilots used the calculated TOW of 52.9 t from the bugcard, which was 10 t lower than the TOW on the LTS, as source for the performance calculation. The TOW of 52,9 t was then corrected to a performance TOW of 55,5 t because of performance weight penalties originating from the use of bleed air[10] and a lower than standard QNH[11].

Based on the TOW of 55.5 t the TL-tables showed that a take-off with flaps five, engine bleeds on and an assumed thrust reduction temperature of 60 degrees Celsius, a maximum reduced thrust setting according to the TL-tables, was possible from both the beginning of runway 05 and from intersection S3 assuming the zero wind column. The pilots chose intersection S3 for departure (*see figure 2*).

FMS programming
The pilots entered the performance data in the Flight Management System (FMS) through the relevant pages of the Flight Management Computer (FMC). The captain and first officer verified and crosschecked the entries and found them to agree. The FMS had computed the correct weight figures, corresponding to those on the LTS. The take-off

10 Bleed air is compressed air taken from the compressor stages of the engines, which is used for various aircraft systems. The use of bleed air during take-off implies a performance penalty.
11 QNH is the reference atmospheric pressure adjusted to sea level.

speeds were consequently derived from the FMC after entering the 60 degrees Celsius assumed temperature. A clearway-stopway correction of 1 kt was then applied to the take-off decision speed V1. The take-off speeds were based on the correct take-off weight.

2.2.3 Flight

Take-off in Groningen

Off-blocks time was at 15:07, eighteen minutes earlier than the scheduled off-blocks time. The captain stated in an interview that the crew did not experience time pressure. The pilots conducted a short line-up[12] from intersection S3 of runway 05 for take-off (see *Figure 2*) and the first officer, as pilot flying, initiated the take-off.

During the take-off roll, above 80 knots, the pilots realised that the acceleration was less than expected. The captain tried to analyse what was going on and the first officer asked the captain if all was normal. The captain assessed the situation and deemed that there was not enough runway length remaining to safely abort the take-off. This was not communicated verbally. The pilots continued the take-off. When nearing the end of the runway the first officer (who acted as Pilot Flying) announced the intention to start rotation early. Nevertheless, rotation occurred at the calculated rotation speed.

No additional thrust was selected and the aircraft became airborne approximately 60 metres[13] (see Appendix C, Figure 1) before the end of runway 05 at 15:15.

Onwards to Rotterdam

Once airborne, the flight crew discussed the occurrence and discovered the calculation error of the TOW on the bugcard.

The remainder of the flight was uneventful according to the pilots. At 15:53 the aircraft landed at Rotterdam. There was no damage to the aircraft and no injuries to either crew or passengers. The pilots filed an Air Safety Report of the occurrence.

2.2.4 Flight crew

The captain had been in service with the operator since 2003. As from July 2014 he had been employed as captain on the Boeing 737. Prior to the incident the captain had accumulated 148 hours in function. The captain had been to Groningen multiple times. The last time was one week prior to the incident. The captain stated that runway 23 was usually in use.

The First Officer had been in service with the operator since February 2014. The first officer had been to Groningen twice in the previous six months. Both times runway 23 had been in use.

12 A short line-up consumes less runway length for lining up the aircraft with the runway prior to departure.
13 From the ACMS data, using the GPS coordinates, single integration of ground speed and line-up distance corrections for intersection S3, the take-off run distance was calculated as 1,740 m. This means that there was approximately 60 m of runway length remaining at lift-off.

Both flight crew members had a valid Boeing 737 300-900 type rating. They flew Boeing 737-700 and Boeing 737-800 interchangeably, but mostly Boeing 737-800. During the 3.5 months before the incident flight the captain flew Boeing 737-800 in 86% of the stretches and the first officer in 93% of the stretches.

	Captain	First Officer
Types flown:	Boeing 737-700/800	Boeing 737-700/800
Total flying hours:	9559	610
Hours on type:	6875	422
Hours in function:	148	422
# stretches on Boeing 737-800 (1 May – 18 Sept 2014):	70	86
# stretches on Boeing 737-700 (1 May – 18 Sept 2014):	11	6
Consecutive number of stretches on the 737-800 before the incident:	30	40

Table 4: Flight crew experience on Boeing 737-700 and 737-800.

2.2.5 Aircraft
The aircraft was a Boeing 737-800. The pilots reported that all relevant systems operated properly during the flight.

Weight and balance
The TOW and CG were within the aircraft's authorised structural limits.

Operating Weights Boeing 737-800	Incident flight	Maximum
ZFW:	58,838 kg	62,731 kg
TOW:	62,838 kg	78,975 kg

Table 5: Relevant incident flight and maximum aircraft operating weights.

2.2.6 Meteorological information
During flight preparation, the pilots recorded the weather information from the Automatic Terminal Information System (ATIS) onto the bugcard. This information showed an average wind direction of 100 degrees, varying between 060 and 170 degrees. The steady wind speed was 5 kt, varying between 3 and 11 kt. The visibility was more than 10 km, with few clouds and no rain. The barometric pressure was 1011 hectopascal (hPa).

2.2.7 Aerodrome
Groningen Airport Eelde (elevation 18 ft) has two runways (see *Figure 2*). Runway 01-19 is 1,500 m long and runway 05-23 is 2,500 m long. The length of runway 05 from intersection S3 is 1,800 m. To use the full length of runway 05, a backtrack from intersection S3 to the beginning of runway 05 is required.

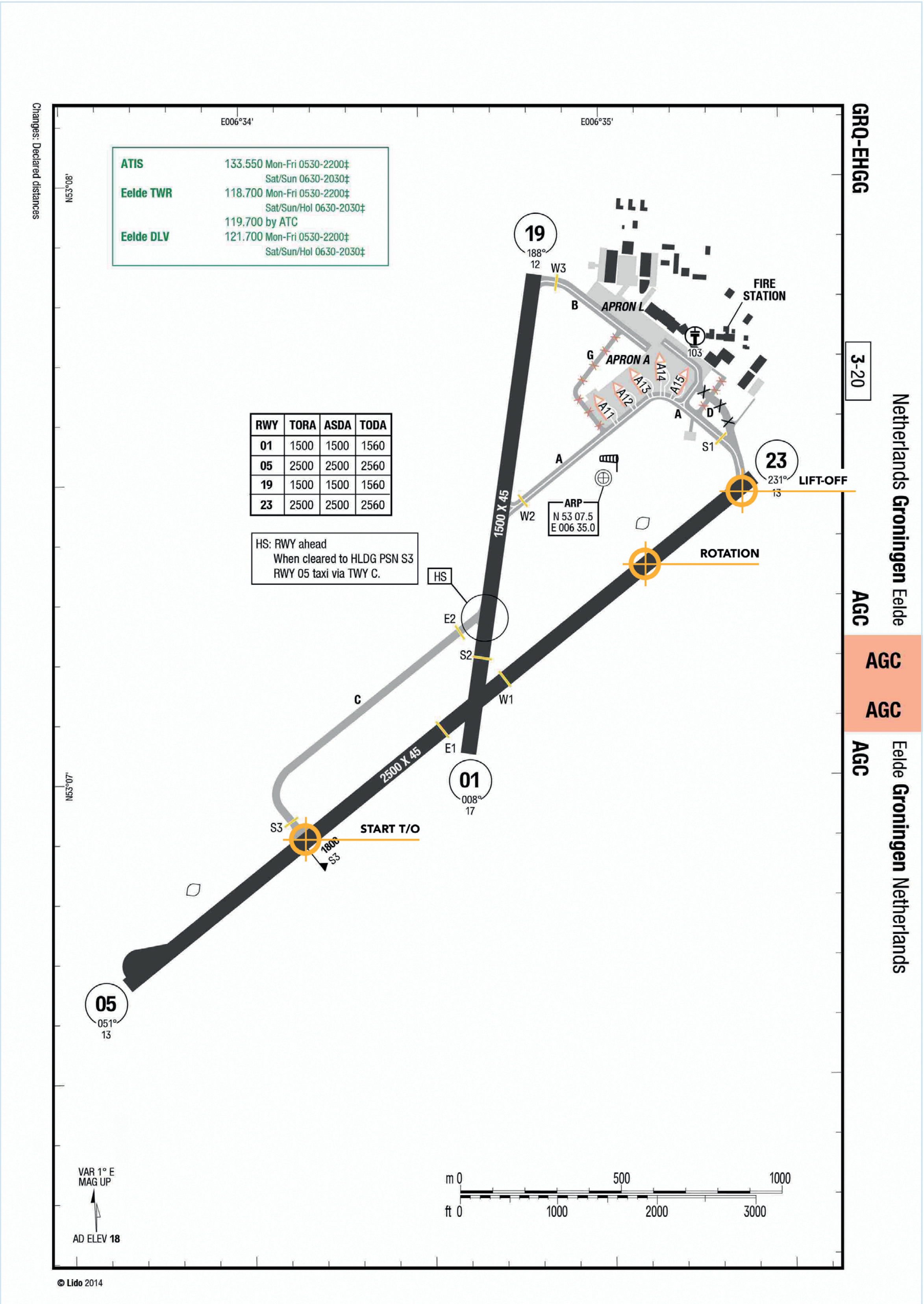

Figure 2: Groningen Airport Ground Chart, the Start T/O, Rotation and Lift-Off positions are marked.

2.3 Lisbon incident

2.3.1 General information
The flight crew was operating on a scheduled two sector passenger service, from Schiphol to Lisbon and back. The flight crew checked in at Schiphol at 15:30.[14]

The first officer was the pilot flying on the sector from Schiphol to Lisbon. The captain was pilot flying from Lisbon to Schiphol. The first sector was uneventful, landing runway was runway 21. The aircraft arrived 7 minutes behind schedule in Lisbon at 18:32 (on blocks time). The aircraft departed Lisbon at 19:28, 8 minutes behind schedule.

2.3.2 Flight preparation in Lisbon
Weight and Balance calculation
During the flight preparation the captain entered the flight data in the EFB for the weight and balance calculation. The first officer crosschecked the outcome of the calculation. The actual ZFW and actual TOW from the EFB calculation were both 2.6 t lower than the weights on the (predicted) OFP. This was observed and accepted as the traffic load was less than predicted on the OFP.[15]

Take-off or landing data card
After completion of the weight and balance procedure, the relevant information was copied onto the bugcard.

Performance calculation
At Lisbon, position 3 of runway 21 was in use for take-off.[16] The pilots individually used the EFB performance module on their respective EFBs for the take-off performance calculation. Both pilots selected position 3 of runway 03 instead of position 3 of runway 21 (see Figure 4). However, they were both under the impression that they had selected position 3 of runway 21.

According to the calculated take-off performance an improved climb[17] take-off was possible with flaps 5 and an assumed temperature of 65 degrees Celsius (see also Figure 6).[18] The pilots checked that the performance calculation results agreed with each other.

FMS programming
The pilots entered the performance data in the FMS through the relevant pages of the FMC. The captain and first officer verified and crosschecked the entries.

14 Local time in Lisbon was UTC.
15 The EFB calculation is based on the actual load data, while the OFP is based on the predicted loads.
16 The Lisbon AIP stated: *When Runway 21 is in use, the preferred departure position for all aircraft, except for heavy jets, should be Position 3 – U5 intersection. Pilots shall advise ATC on Start-up when full length is required.* This information was also broadcasted on the ATIS.
17 Improved climb is a method to increase the performance limited take-off weight, whenever a take-off is climb or obstacle limited.
18 The EFB provides calculations with a higher assumed temperature than possible when using the TL-tables as in the Groningen incident, provided the thrust reduction in N1 is not more than 25%. This is due to the accuracy of the EFB calculation.

2.3.3 Flight

Take-off in Lisbon

Off-blocks time was at 19:14, nine minutes later than the scheduled off-blocks time. The captain stated during an interview that because he had only recently been promoted to captain he felt susceptible to time pressure. The pilots used intersection U5 of runway 21 for take-off (position 3) and the captain, as pilot flying, initiated the take-off.

Towards the end of the take-off roll (just prior to V_1) both pilots realised that the take-off roll was longer than expected. They did not communicate this to each other. Both pilots were convinced that the remaining runway length would be sufficient to become airborne. No additional thrust was selected and at 19:28 the aircraft became airborne approximately 430 m[19] (see Appendix C, Figure 2) before the end of runway 21.

Onwards to Schiphol

Once airborne the flight crew discussed the occurrence and discovered the error of the runway position selection on the EFB.

The remainder of the flight was uneventful. There was no damage to the aircraft and no injuries to either crew or passengers. The pilots filed an Air Safety Report of the occurrence.

2.3.4 Flight crew

The captain had been employed by the operator since 2002. As from November 2015 he was employed as captain on the Boeing 737. The first officer had been employed by the operator since November 2007. Both pilots had been to Lisbon multiple times. They stated that runway 03 had generally been in use for take-off and landing.

The flight crew members had a valid Boeing 737 300-900 type rating. They flew Boeing 737-700 and Boeing 737-800 interchangeably, but mostly Boeing 737-800. During the four months prior to the incident flight the captain flew Boeing 737-800 in 89% of the stretches and the first officer in 91% of the stretches.

19 From the ACMS data, using the GPS coordinates, single integration of ground speed and line-up distance corrections for intersection PSN 3, the take-off run distance was calculated as 1,980 m. This means that there was approximately 430 m of runway length remaining at lift-off.

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	Captain	First Officer
Types flown:	Boeing 737-700 / -800	Boeing 737-700 / -800
Total flying hours:	11,200	5,325
Hours on type:	8,100	5,040
Hours in function:	200	5,040
# stretches on Boeing 737-800 (1 August – 3 December 2015):	54	79
# stretches on Boeing 737-700 (1 August – 3 December 2015):	7	7
Consecutive number of stretches on the 737-800 before the incident:	16	36

Table 6: Flight crew experience on Boeing 737-700 and 737-800.

2.3.5 Aircraft

General

The aircraft, a Boeing 737-800, was certified, equipped and maintained in accordance with the existing regulations and approved procedures. The pilots reported that all relevant systems operated properly during the flight.

Weight and balance

The TOW and CG were within the aircraft's authorised structural limits.

Operating Weights Boeing 737-800	Incident flight	Maximum
ZFW:	57,793 kg	62,731 kg
TOW:	65,993 kg	78,975 kg

Table 7: Relevant incident flight and maximum aircraft operating weights.

Electronic Flight Bag (EFB)

The aircraft was equipped with navAero tablet style computers as EFBs which remain with the aircraft as ancillary equipment (see Figure 3). The system is installed at both captain and first officer stations in the cockpit and is capable of displaying documents and running applications. The left and right EFB can communicate with each other through a crosslink connection.

The input parameters for the performance calculation cannot be communicated through the crosslink.

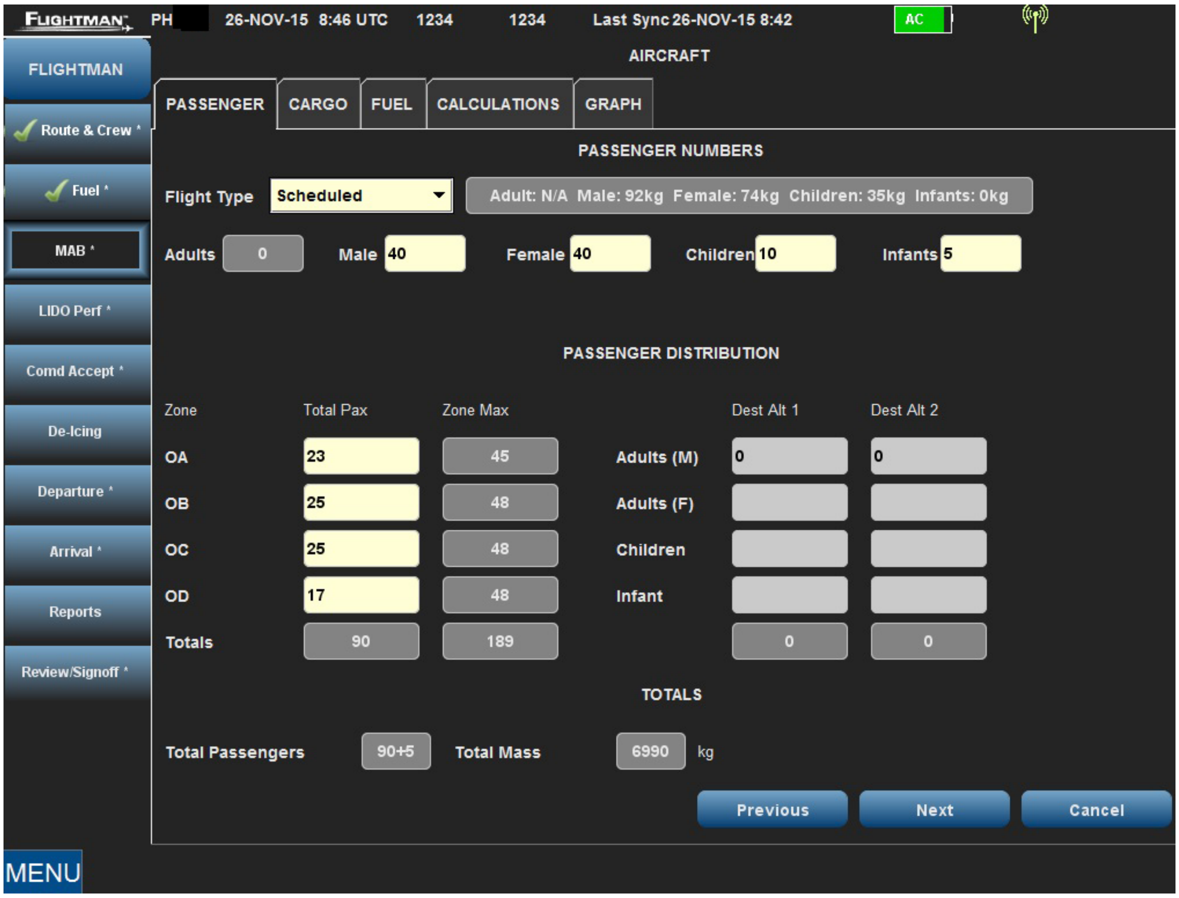

Figure 3: EFB weight and balance (MAB) screen with selectable tabs on the left-hand side.

During normal operations the weight and balance and the take-off performance applications (*MAB and Lido Perf*) of the EFB replace the manual load and balance procedure and the TL-tables for the performance calculation. The manual load and trim and performance procedures are still in use as part of the back-up procedure in case of inoperative EFBs.

2.3.6 Meteorological information

The ATIS information showed that it was a clear evening, dry weather, no low clouds and a barometric pressure of 1029 hPa. The average wind direction was 280 degrees, varying between 010 and 240 degrees. The steady wind speed was 3 kt. Both pilots elected to use the L&V (light and variable) setting for the wind speed and direction in the performance module on the EFB. This setting assumes a 5 kt tailwind component in the performance calculation.

The wind given by Air Traffic Control (ATC) in the take-off clearance was variable (in wind direction) with 3 kt. The incident happened during night-time conditions.

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2.3.7 Aerodrome

Lisbon Airport (elevation 374 ft) has two runways (see Figure 4), runway 17-35 is 2,315 m in length and runway 03-21 is 3,705 m long. Position 3 of Runway 21 was in use for take-off, which was broadcasted on the ATIS. The Take-Off Run Available (TORA) of runway 21 from position 3 was 2,410 m. In order to use the full length of runway 21, the runway has to be crossed first. The TORA of runway 03 from position 3 was 3,530 m.

The naming of the take-off positions was not unique at Lisbon Airport. Both runway 03 and runway 21 had an intersection named position 3. At most airports the identifier of the take-off position consists of a unique character/number combination (e.g. the runway intersection designator), as recommended in the Airports Council International Runway Safety Handbook[20], paragraph 2.4: *ACI recommends that a taxiway accessing a runway should be identified by a code consisting of a letter followed by a figure (e.g. A1, A2, A3 … A12), beginning with 1 but not 0, from the extremity of the runway and continuing without missing a number.* During the investigation the operator provided this information to the Lisbon Runway Safety Team regarding coding of taxiways accessing runways.

The GPIAA and the Lisbon Runway Safety Team, in cooperation with other operators and airport representatives, identified and investigated this hazard. The GPIAA sent a proposal to the Lisbon Airport management to remove conflicting take-off positions and rename the positions with reference to their unique taxiway entry. At present, the take-off intersections of Lisbon Airport have been renamed, see Table 8.

Runway	TORA (m)	Take-off intersection name at time of incident	Revised take-off intersection name
03	3,705	PSN1	PSN M
	3,615	PSN2	PSN N
	3,530	PSN3	Removed
	3,005	PSN4	PSN P
21	3,805	PSN1	PSN S
	3,705	PSN2	Removed
	2,410	PSN3	PSN U

Table 8: Renamed take-off positions of runway 03/21.

20 Airports Council International, Runway Safety Handbook, 1st edition, published in 2014.

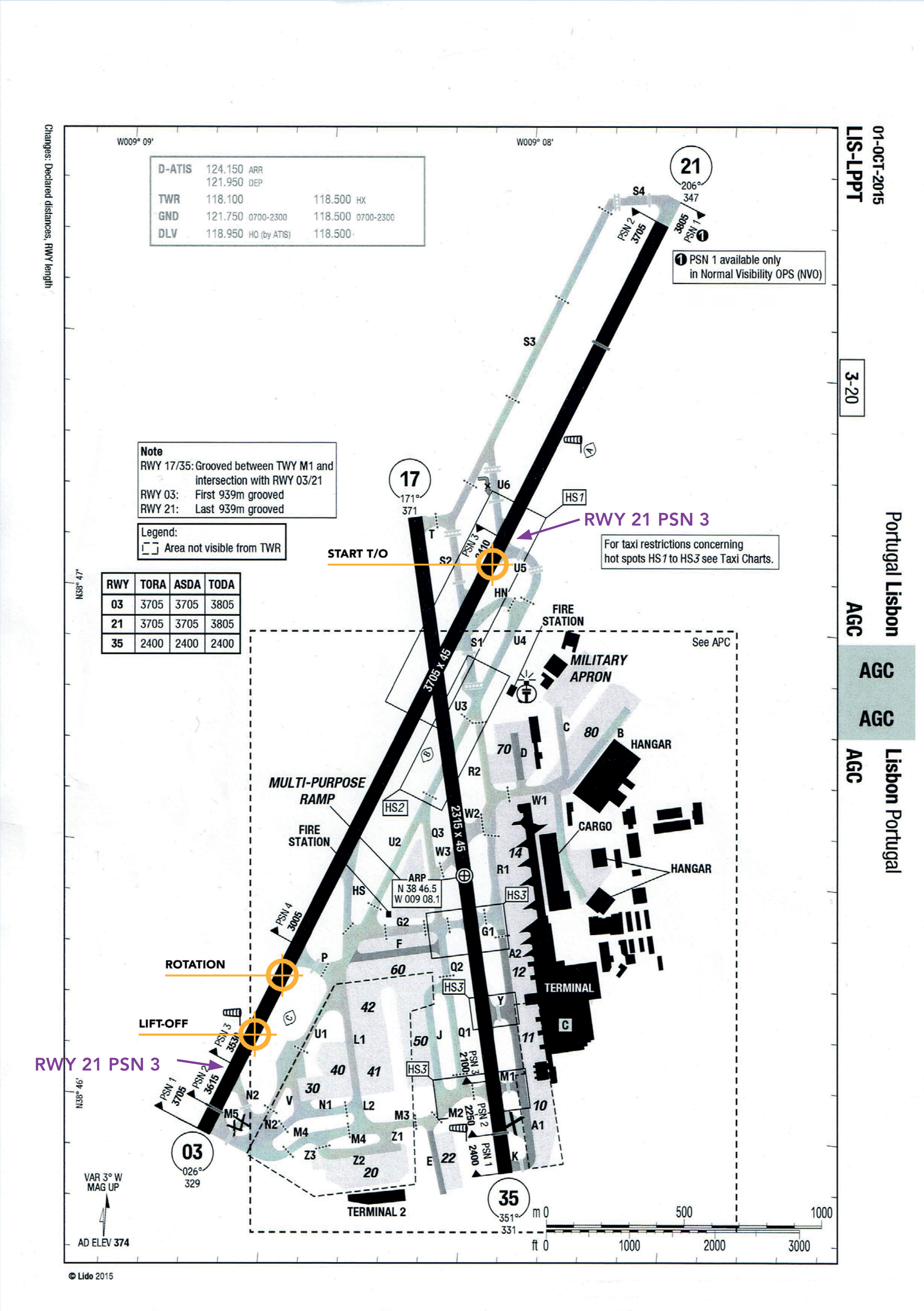

Figure 4: Lisbon Airport Ground Chart, the Start T/O, Rotation and Lift-Off positions are marked.

2.4 Organisational and management information

2.4.1 The manual Load and Trim and performance procedure

During the Groningen incident, the manual load and trim and performance procedure were in place, in which pilots had to complete the LTS manually, using the actual load data from the Flight Crew Information Sheet.[21] Amongst other things, the aircraft weights are determined on the LTS. These weights can be transferred onto the bugcard. The performance calculation was to be made after the load and trim calculation was completed.

Manual Load and trim sheet

The manual LTS in use by the operator at the time of the Groningen incident requires information about the amount and location of passengers and cargo as well as the amount of fuel. The LTS enables the flight crew to determine the aircraft weights and the location of the centre of gravity. The weight figures have to be computed manually by the flight crew. The centre of gravity can be determined by completing a diagram using the passenger and cargo distribution throughout the aircraft (see Appendix A, Figure 1).

In the Lisbon incident the manual LTS was replaced by a computerized loadsheet.

The take-off or landing data card / bugcard

The operator uses a bugcard on which, amongst other things, flight crews can note the results of the manual LTS (see Appendix A, Figure 2). The bugcard has been used as a notepad to gather take-off or landing related information for more than twenty years. The bugcard is not part of the standard Boeing procedures or documentation. Therefore the operator had to set up the use of the bugcard. The Operations Manual-Part A (OM-A, see Appendix B, Figure 1 OM-A 8.1.12-14) states that the bugcard has to be completed for each flight. Either pilot can enter information on the bugcard. Although the Operations Manual states that filling in the aircraft's take-off weight and zero fuel weight is not required, it does strongly recommend flight crews to do so.

The manual performance procedure

The Flight Crew Operations Manual (FCOM), Flight Crew Training Manual (FCTM) and Performance Manual (PM) do not prescribe which source (e.g. LTS, OFP, FMC, bugcard) should be used for the TOW in the performance calculation. Both pilots of the Groningen incident stated they were instructed to use the TOW from the bugcard for the performance calculation during their initial training with the operator.

The take-off performance is calculated using TL-tables and the take-off speeds are calculated by the FMC (corrections are applied to these speeds in certain conditions).

21 The FCIS contains information about the actual load, and distribution of that load, for a flight. The FCIS is completed by a handling agent after the check-in process is completed.

Crosschecking procedures
Crosschecking procedures are described in the FCOM (see Appendix B, Figure 2) and the FCTM (see Appendix B, Figure 3). The FCOM gives general guidelines and some specific examples of items to be crosschecked. For the weight information it is specified that the ZFW of the flight plan, weight and balance calculations and the FMC (CDU) should be crosschecked against each other. The FCTM also emphasizes the need to crosscheck and specifies similar items as the FCOM. The FCOM does not describe a crosscheck on the aircraft's weights filled in on the bugcard.

The Amplified Procedures paragraph in the Normal Procedures section of FCOM1 (see Appendix B, Figure 4) specify that the gross weight on the dispatch papers and the FMC (CDU) should be crosschecked to agree.

Pilot intervention
The Boeing 737 FCTM states that if conditions are encountered during the take-off where additional thrust is needed, such as a windshear condition, the crew should not hesitate to manually advance thrust levers to full rated thrust.[22]

2.4.2 EFB introduction and procedures
The operator made use of EFBs for load and balance and performance calculations during the Lisbon incident. The EFBs replaced, amongst others, the manual load and trim sheet and manual performance calculations. The plans for the introduction of the EFB started in 2011, in follow up to a previous proposal in 2005. For the hardware the operator chose the navAero T-Bag C2 portable/removable personal computer. As main operating package, the Flightman software was chosen. The Lufthansa Lido software was selected for the performance calculation tool and navigation charts. The operator chose the standard lay-out of the performance tool. The operator also decided to use and maintain their own airport data file[23] for the performance tools.

The operator split the introduction of the EFB into three phases; phase one contained the digitalised navigation maps and manuals, in phase two the electronic weight and balance procedure and performance calculation procedures were added. Phase three will incorporate new features and more automation, such as the pre-loading of data. In November 2014 the operator completed phase two for its entire fleet. At the time of the Lisbon incident phase one and two were implemented.

Before and during the introduction, the operator published several documents and an instruction video to familiarise its pilots with the use of the EFB. The use of the EFB was also addressed during simulator training.

22 When a fixed derate method is used however, pilots should observe operating limits with regard to minimum control speeds when advancing the thrust levers beyond the fixed derated thrust. When using an assumed temperature take-off method, no problems with minimum control speeds are to be encountered when advancing to full take-off thrust as the minimum control speeds will be based on full take-off thrust. Both the Groningen and Lisbon takeoff where conducted according the assumed temperature takeoff method.

23 The airport data file contains runway specific information, such as distances, numbers and intersection identifier names.

With the introduction of the EFB, sections were added to the FCOM and FCTM on the use of the EFB. These sections particularly specify the task distribution between pilots and crosschecking procedures when using the EFB. The FCTM sections also provide more clarification on these individual tasks (see Appendix B, figure 3). The FCOM and the FCTM describe that both pilots independently carry out the performance calculation with the performance module of the EFB. The crosscheck of the performance calculation is the comparison of the outcome of the two independent performance calculations.

The operator kept the manual load and trim and performance procedure in place as a back-up for the EFB procedure in case of a malfunction of the EFB equipment.

2.4.3 Evaluation of crosschecking procedures by the operator

The operator indicated to assess and evaluate procedures in two occasions; in case of changes and in case of issues or incidents. The evaluation process does not take place periodically, but is mainly based on observed problems. Line Operations Safety Audits (LOSA) form an exception.

Since the introduction of the Safety Management System (SMS) in 2013, the operator has carried out risk assessments when procedures or equipment change.

The operator stated that procedures are constantly adjusted due to issues and incidents. These changes stem from incident investigations, trends analysis from Flight Data Monitoring (FDM) and issues reported by the operator's employees in debriefs. Evaluation of the procedures is based on observed problems and takes place in safety and quality board meetings, safety action group meetings, FDM meetings and SOP (Standard Operating Procedures) meetings.

Evaluation of the manual Load and Trim Sheet procedures

The operator carried out an investigation into data entry errors in 2014 based on a FDM data and ASR analysis. It was concluded that one of the causes of error propagation was a non-executed or non-effective crosscheck. One of the recommendations was to review flight preparation and crosschecking procedures. A second recommendation was aimed at training crews in effective crosschecking. As follow up, the main objective of the training department was to emphasize the correct execution of crosschecking procedures.

The operator did not review the manual load and trim procedures after the Groningen incident (18 September 2014), because shortly after the incident the second phase of the EFB was introduced. The EFB procedures replaced the manual LTS and performance procedures.

Assessment and evaluation of EFB procedures

A number of pilots were involved in a safety assessment concerning the introduction of the performance tool on the EFB in an early stage of the EFB project (in 2012). They were asked about skill training, knowledge aspects and procedural changes.

In January 2013, the operator performed three risk assessments for the EFB prior to its introduction. The EFB hardware and software were not available for the risk assessments. The participants[24] remarked in the risk assessment reports that the absence of EFB hardware and software made it difficult for them to identify hazards and assess the risks of these hazards. Particularly hazards related to ergonomics could not be addressed according to the participants. Screenshots of the to be installed applications where used to identify hazards related to ergonomics instead.

The risk assessments (2013) and the safety assessment (2012) identified several medium and high risk hazards. For the weight and balance procedures these hazards were identified as crosschecking and data input error related. The associated mitigating actions were Standard Operating Procedures (SOPs) and training. For the take-off performance calculation procedure these hazards were identified as data input error, knowledge and aircraft configuration related. The associated mitigating actions were crosschecking and training.

After the introduction, the EFB procedures continued to be adapted as a result of feedback from the SMS (air safety reports, debriefs and flight data monitoring). The operator was aware that input errors were being made in the operation of the EFB because of continuous monitoring of the operation as part of the operator's SMS.

2.5 System automation

The Dutch Safety Board also looked into system automation as possible barrier against performance related take-off incidents. There are two types of systems for automated performance calculations, namely centralised automated systems and on-board systems (see Appendix E for more information about these systems).

The operator does not use a centralised system for remote automated performance calculations. A remote automated performance calculation is also not likely to have prevented the occurrence in Lisbon since this was a selection error of the runway and take-off position in use. The current remote automated performance calculations cannot check whether the selected runway and take-off position are correct and will perform a performance calculation based on the input of the flight crew. A selection error of the runway in use would thus still be possible.

The aviation industry is continuously searching for systems to reduce the number of take-off related incidents and accidents. On-board weight and balance systems, such as an autonomous On-Board Weight and Balance System (OBWBS) and Take-off performance monitoring systems (TOPMS or TOPM) are not common yet. Neither of these systems were in use by the operator around the time of the incident, nor were they available for Boeing 737 aircraft. A TOPMS has not been certified for any type of aircraft.

24 The participants for the three risk assessments consisted of employees of the various flight departments and nine line pilots.

On-board 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) for the weight and balance values used in the performance data process.

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

2.6 Rules and regulation

2.6.1 Priority of data-entry incidents and accidents

In 2016, EASA carried out an operational risk assessment (ARMS methodology) in order to prioritise the problem of erroneous data-entries relative to other safety issues it has been working on. A quantitative analysis on data-entry incidents and accidents that were investigated in the period 1999-2015 was carried out. EASA also analysed the trends, severity (number of fatal injuries), outcome (for instance runway excursion), and contributing factors of 31 investigated incidents and accidents. Based on this analysis EASA set up a risk matrix. Due to the limited number of accidents with fatal injuries (three accidents over 16 years), the priority to develop the regulatory framework in order to reduce the risks of erroneous data-entries was found to be low relative to other safety issues. Based on the ARMS methodology, the risk level and its trend need to be monitored continuously in order to prevent escalation to an unacceptable level, and reinforcement of existing measures and introduction of new measures should be considered.

2.6.2 Prioritising actions in relation to the prevention of data-entry incidents and accidents

EASA uses a tool, named Preliminary Impact Assessment (PIA), to rank agency actions (rulemaking, safety promotion, industry standard, oversight, research) for the problem of erroneous data-entries. This tool takes into account effectiveness (potential safety improvement), cost effectiveness (a measure must be proportional) and implementation time. EASA reported that three types of actions were assessed or will be assessed:

1. *Safety promotion:* This action scored high on safety benefits (due to the positive effect of FDM event monitoring), as well as on cost effectiveness and implementation time. It has already been implemented; EASA published a Safety Information Bulletin (SIB 2016-02) with operational guidelines on training, FDM event monitoring and safety risk analysis and assessments by operators.
   On request of EASA, the Netherlands Aerospace Centre (NLR) performed a study into *Best practices for approval of performance and Mass and Balance applications on EFBs*[25] (see paragraph 2.6.4), which was made available on EASA website as a safety promotion action.
2. *Technical solutions (Industry standards):* This measure scores high on risk reduction (50%-100%), but lacks cost estimates and implementation time is uncertain.
3. *Improve the use of EFB:* EASA formulated Acceptable Means of Compliance 20-25 (AMC 20-25) on EFBs[26]. Other rulemaking tasks (RMT.0601 & 0602) are in progress regarding Transposition of Provisions on EFBs from ICAO Annex 6 *Operation of Aircraft into EASA regulations*. RMT.0601 is planned to be completed in September 2017. The main changes introduced are the introduction of an operational approval for the use of EFBs[27] by commercial air transport operators and the transposition of the operational elements of AMC 20-25 into EASA Air Operations Part-CAT and Part-SPA. There are only minor changes between AMC-20-25 and the proposed amendments included in RMT.0601.

2.6.3 System automation

EASA received nine safety recommendations regarding system automation since 2006. Two European Organisation for Civil Aviation Equipment (EUROCAE)[28] working groups (WG-88 and WG-94) investigated the feasibility of establishing standardisations and performance specifications for both OBWBS and TOPMS. One working group (WG-106) has been set-up to deliver Minimum Operational Performance Standards (MOPS) for EFB applications.

WG-88: On-Board Weight and Balance Systems (OBWBS)

In 2013 WG-88 concluded that the standardisation of an OBWBS specification was feasible and recommended. However the report did not provide such specifications or any requirements to install such systems into existing or future aircraft. EUROCAE continued facilitating WG-88 in order to develop MOPS - industry standards for OBWBS. Once the MOPS are delivered, EASA aims to launch a rulemaking activity to propose mandating and/or facilitating the installation of OBWBS.

25 R.S. Tump, G.W.H. van Es, A.K. Karwal and M.J. Verbeek (NLR), *Best practices for approval of Performance and MB applications on EFBs*, Final Report EASA_REP_RESEA_2014_1, 2015.

26 EASA, AMC 20-25; Airworthiness and operational consideration for Electronic Flight Bags (EFBs), 2014.

27 Operational approvals were previously required by some member states of EASA, but no requirement for operational approvals was stated in the EU regulatory framework.

28 EUROCAE is an independent association. EUROCAE makes industry standards for aviation. Membership is open to manufacturers and users of equipment for aeronautics, trade associations, national civil aviation administrations, and, under certain conditions, non-European organisations. Its work programme is principally directed to the preparation of performance specifications and guidance documents for civil aviation equipment, for adoption and use at European and worldwide levels.

WG-94: Take-Off Performance Monitoring Systems (TOPMS)
In February 2015 WG-94 concluded that it was not possible to initiate standardisation activities for TOPMS within EUROCAE at that moment. This was due to a multitude of factors, including the maturity of the technology, a lack of real-time data, and/or suitable aeroplane performance models, a lack of consensus in design criteria and testing methods. EUROCAE will monitor the progress of technical solutions. It was recommended to evaluate this situation in 3 to 5 years. After evaluation in February 2017, this working group remained on hold.

WG-106: Electronic Flight Bag (EFB)
Based on existing material, WG-106 will identify the minimum requirements that any EFB software application must meet. It will also develop testing criteria and consider the progress of current EFB rulemaking activities by EASA. WG-106 is scheduled to deliver MOPS for EFB software applications in 2018.

2.6.4 Improvement of the use of EFB
In a study for EASA[29], the NLR pointed out that detailed information about the hazards of using an EFB for weight and balance and take-off performance calculations is lacking. AMC 20-25 provides rather high-level guidance on human factor issues (such as ergonomics), leaving the challenge of applying the principles to the operator. The NLR made the following recommendations to EASA, relevant for this investigation:

- Regulators should be made aware that errors in pilot entry into EFB applications are the most common factor in EFB-related incidents. Applied to performance and mass and balance applications, this can lead to erroneous critical flight parameters.
- To consider performing uninvited (e.g. initiated by EASA) and limited-scope evaluations of commercially available take-off and landing performance and mass and balance applications targeted only at human factors issues. In addition, to increase the regulators expertise, it is suggested to organize (a) workshop(s) at EASA on human factor issues.
- To distribute to regulators a hazard and proposed mitigation measures list of using an EFB for mass and balance and take-off and landing performance calculations or to include it in ICAO Annex 6 Operation of Aircraft.

29 R.S. Tump, G.W.H. van Es, A.K. Karwal and M.J. Verbeek (NLR), *Best practices for approval of Performance and MB applications on EFBs*, Final Report EASA_REP_RESEA_2014_1, 2015.

3 ANALYSIS

3.1 Introduction

The thrust settings that were selected in both the Groningen and the Lisbon incident were less than required as a consequence of incorrect performance calculations. In the Groningen incident a miscalculation caused the insufficient thrust setting, whereas the Lisbon incident was caused by an incorrect runway/intersection selection. Although the type of errors were different, the existing crosschecking procedures and barriers designed to prevent these incidents, with which the flight crew complied in both incidents, failed to catch the errors in time.

3.2 Groningen Incident

3.2.1 Direct cause

The performance calculation was based on a TOW that was 10 t lower than the actual TOW of 62.9 t and a wind component of 0 kt. The actual take-off thrust, resulting from the performance calculation, was therefore less than the required take-off thrust setting. As a consequence none of the required safety margins were met (see Appendix D, Figure 1)[30]. An engine failure at V_1 would have resulted in a runway excursion. Even without an engine failure, the available runway length was 68 m too short for the required take-off run distance according to aircraft manufacturer Boeing.[31] Boeing calculated the take-off distances for the same thrust setting and conditions as the incident flight. The fact that the aircraft became airborne approximately 60 m before the end of the runway can be attributed to the fact that these calculations use conservative assumptions.[32]

The take-off speeds were calculated for the correct take-off weight as they were derived from the FMC, which was programmed with the correct weight figures. However, the erroneous assumed temperature of 60 degrees Celsius was also programmed into the FMC.

30 Boeing calculated the take-off distances for the same thrust setting and conditions as the incident flight.
31 Boeing calculations, see Appendix D.
32 Boeing stated the following about thrust and drag:
• Thrust; there is variation in takeoff thrust between engines due to manufacturing build tolerances. The Boeing calculations are based on the minimum expected thrust from a conforming engine.
• Drag; most of the AFM aerodynamic parameters are based on a forward CG to be conservative for distances and climb gradients. The drag in the calculations performed above is based on a forward CG. The actual CG of 18.6% MAC would have provided a drag benefit. Boeing does not have sufficient flight test data to substantiate an exact amount of drag credit for the actual CG.

From the pilots perspective intersection S3 of runway 05 was a valid choice for take-off. Their performance calculation, using the erroneous 10 t low takeoff weight, showed that both a take-off from the beginning of the runway and from the intersection were possible with the same thrust reduction. Taking-off from the intersection saved time and improved the flow of traffic, as no back track was required on the runway.

The weight used for the performance calculation was the weight as written on the bugcard, which was 52,9 t. Performance penalties for the use of bleed air and a lower than standard QNH were correctly applied to this weight. Hence, the weight used in the performance tables was 55,5 t. The flight crew used the zero wind column in the performance tables to find the maximum assumed temperature at which the engines would provide sufficient thrust for a safe takeoff. This showed a temperature of 60 degrees Celsius, which was the maximum temperature noted in the performance tables. When entering the performance tables with the correct takeoff weight, adjusted for performance penalties to 65,5 t, the tables show an assumed temperature of 30 degrees Celsius. The thrust setting corresponding to an assumed temperature of 30 degrees Celsius is significantly higher than the thrust setting corresponding to an assumed temperature of 60 degrees Celsius and would have been sufficient for a safe takeoff in windless conditions.

The wind, according to the ATIS, was from direction 100 degrees with a steady component of 5 kt, but variable in direction between 060 and 170 degrees and variable in wind speed between 3 and 11 kt. This means that wind from direction 170 degrees with a speed of 11 kt was possible. As runway 05 was in use there was a possibility of a 120 degree angle between the runway heading and the wind direction. At a wind speed of 11 kt this would create a tailwind component of 5,5 kt. Entering the performance tables for a 5 kt tailwind component and the erroneous 55,5 t takeoff weight shows a maximum assumed temperature of 52 degrees Celsius. When entering the performance tables for a 5 kt tailwind and the correct weight of 65,5 t, the performance tables show a temperature of 8 degrees Celsius. As the outside air temperature was 24 degrees Celsius, a takeoff would then not have been possible from intersection S3. A takeoff from the beginning of runway 05 would then have been required. The operator's performance manual does not accurately describe which wind direction and speed should be taken into account in case of a variable wind direction and speed.

Erroneous takeoff weight	Wind factor	Resulting temperature in TL-tables
55,5 t	0 kt	60°C
55,5 t	- 5 kt	52°C

Correct takeoff weight	Wind factor	Resulting temperature in TL-tables
65,5 t	0 kt	30°C
65,5 t	- 5 kt	8°C

Table 9: Used (erroneous)and actual (correct) takeoff weight, two possible wind factors and the resulting assumed temperatures in the TL-tables.

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The ACMS take-off data (Appendix C, Figure 1) shows that groundspeed and calibrated airspeed during the take-off roll were the same, or that calibrated airspeed was higher, indicating no wind or headwind. Just before rotation, between 43 and 47 seconds into the event, the calibrated airspeed is lower than the groundspeed by approximately 4 kt. This indicates tailwind. Although this period is short, a tailwind does negatively influence the performance of the aircraft. The effect of the short period of tailwind however, is minor compared to the effect of the erroneous take-off weight used for the performance calculation.

3.2.2 Contributing factors to the calculation error

Although the bugcard is not designed as a chart on which calculations are to be completed, there is no description of the exact purpose of the bugcard as a reference chart on which only results of calculations are to be noted in the manuals of the operator. The TOW on the bugcard can be calculated by adding the take-off fuel weight to the ZFW[33] or can be transferred directly from the LTS. Choosing to make a TOW calculation on the bugcard is unnecessary, as it has already been calculated on the LTS, and it presents an extra possibility to make a calculation error. Nevertheless this method could be used because of the lacking procedures describing the use of the bugcard. Furthermore, the FMC also displays the TOW after the ZFW as calculated on the LTS has been entered into the FMC. This value could also have been transferred onto the bugcard.

Neither the manuals (FCOM, FCTM), nor the operator, prescribe which TOW source should be used as the source for the performance calculation. In interviews the flight crew stated that pilots develop personal strategies with respect to which TOW is being used for the performance calculation. In this case the pilots used the incorrectly calculated TOW of 52.9 t from the bugcard as source for the performance calculation. Both pilots stated they were instructed to use the TOW from the bugcard for the performance calculation during their initial training with the operator.

Completing the weight and balance, performance calculation and FMC procedures required over twenty manual entries, data transfers and calculations to be performed by the flight crew (see Figure 5). At each individual step there was a potential for making an error. The large number of steps, performed during the flight preparation process, increases the chance for errors.

No indications have been found that flight crew fatigue has been a contributing factor in the calculation error.

33 The weight of the taxi fuel is then disregarded. The weight of the taxi fuel is only minor relative to the TOW.

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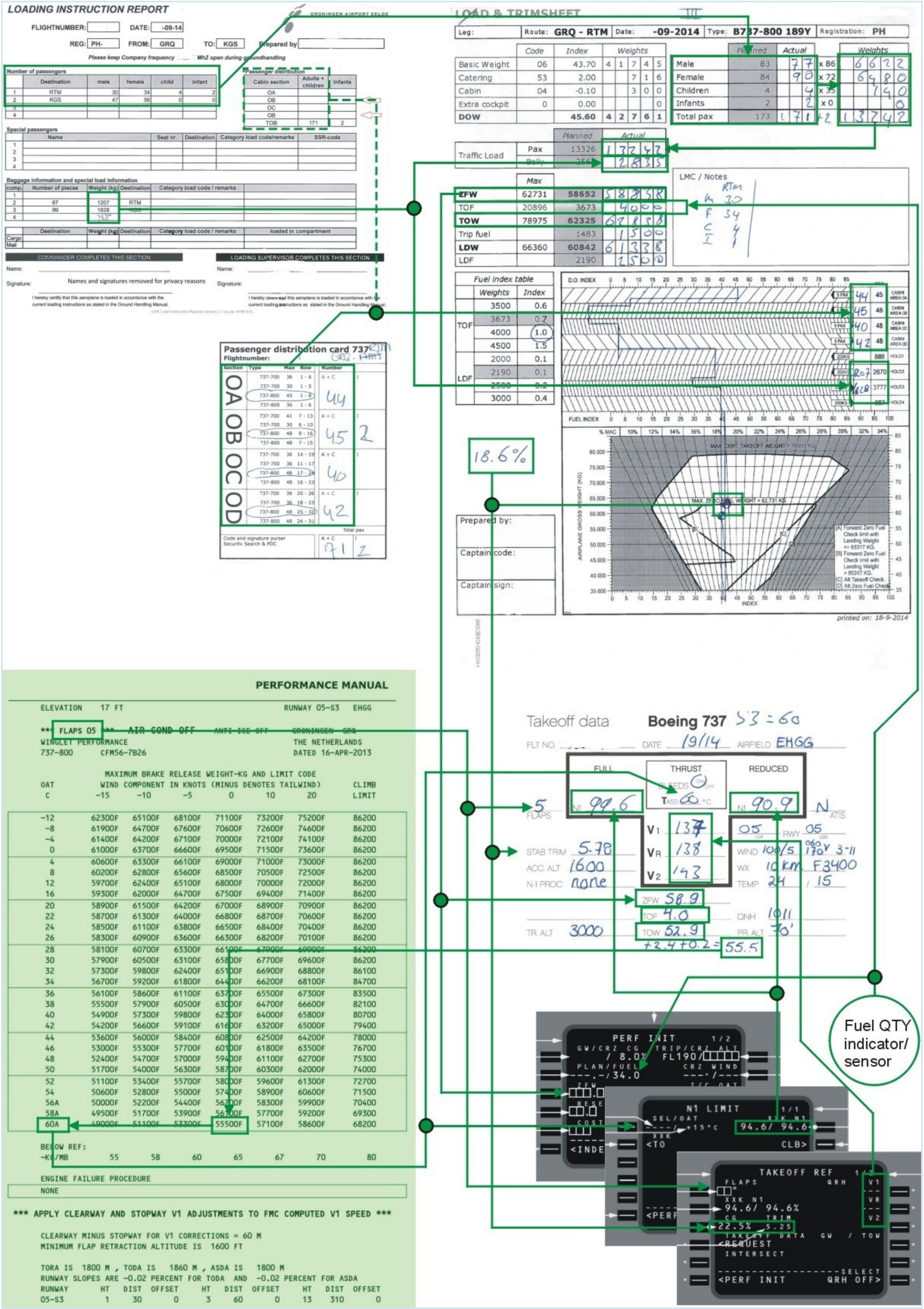

Figure 5: Illustration of the standard data entry and transfer flow (see arrows) for the manual load and balance, performance calculation and FMC procedures during the flight preparation process.

3.2.3 Error propagation

Specific crosschecking procedures

The flight crew performed the required crosschecks according to the procedures in the manuals (FCOM and FCTM). However these crosschecks failed to reveal the calculation error:

- For the ZFW a crosscheck is required between the flight plan, weight and balance calculation and the FMC:
  - *ZFW: OFP = 58.7 t, LTS = 58.9 t, FMC = 58.9 t.*
  - As the ZFW calculation was correct, this crosscheck did not reveal the error.
- Verification that the Gross Weight (GW) on the FMC and dispatch papers agree. This item was also introduced in the before start checklist by the operator after the Groningen incident:
  - *GW: FMC = 62.9 t, OFP = 62.4 t.*
  - The GW on the FMC is automatically calculated by adding the measured fuel weight to the ZFW. As the ZFW entered in the FMC was correct, the resulting GW was also correct (the 0.5 t difference is caused by the difference between the actual and the expected load and the taxi fuel).

After the incident the operator issued an amendment of the Normal Checklist which incorporated a crosscheck of the gross weight of the aircraft between the CDU and the OFP during the 'Before Start' checklist, which is executed prior to engine start. This crosscheck may not be effective in preventing a similar occurrence as the gross weight on the CDU and OFP matched during the incident flight. The TOW used as source for the performance calculation (in case of the Groningen incident, the bugcard), is not an item on the amended Normal Checklist. However, because this amended crosscheck is to be performed in the 'Before Start' checklist, which is generally carried out after the performance calculation, this might serve as a reminder of the correct TOW to the flight crew. This may help them to catch a possible error in the TOW source used for the performance calculation in time.

As shown in paragraph 3.2.2, the TOW on the bugcard may be (and in this incident has been) used for the performance calculation. The operator has not imposed a crosschecking procedure on the bugcard (see paragraph 2.4.1). For crosschecking to be an effective barrier, the relevant data of all available and used sources should be crosschecked with one another. This should at least include a crosscheck between the TOW on the OFP, the source of the TOW used for the performance calculation and the TOW on the FMC. This incident shows that such a crosscheck of the TOW lacks in the manual load and balance and performance procedure. The operator did not change this after the incident (see paragraph 2.4.3) because of the replacement of the manual procedures with the weight and balance module in the EFB. However, the manual procedure still serves as a back-up for the EFB procedure in case of a malfunction of the EFB equipment (see paragraph 2.4.2).

General crosschecking procedures
Pilots are required to crosscheck each other's calculations and data entries. Both the LTS and the bugcard are single forms that are completed by either pilot and checked by the other pilot. The chances of detecting errors on these forms are less likely than when both pilots complete their own forms and compare the results afterwards.

There is only one bugcard and one performance manual available to the pilots. This increases the chance that pilots use them simultaneously and that identical errors are made (as in the Groningen incident, where both pilots used the erroneous TOW noted on the single bugcard as source for their independently executed performance calculations).

3.2.4 Evaluation and revision of the procedures
The operator's internal investigation into data entry errors, which was carried out in 2014, (see paragraph 1.4.3) examined why crosschecks had not been performed or performed in an ineffective way. It notes that no specific guidance is provided for flight crew regarding how effective crosschecking should take place. However, the report does not mention how effective crosschecking can be attained.[34] Whilst the report mentions the possibility of an error on the bugcard, it does not specifically mention the bugcard (or other source used for the performance calculation) should become part of a crosscheck.

The manual load and trim procedures were not reviewed after the Groningen incident, because of the replacement of the manual procedures by the EFB procedures.

3.3 Lisbon incident

3.3.1 Direct cause
The aircraft departed from runway 21 position 3 (U5 intersection) as it was the preferred departure position with runway 21 in use. The runway length from this position was 2,410 m. This is sufficient for take-off with a Boeing 737-800 under normal conditions.

However, the take-off performance was erroneously calculated for a take-off from runway 03 position 3, from which the available TODA was 1120 m longer. As a consequence the available runway length was less than anticipated in the performance calculation and the subsequent thrust setting was not sufficient to meet the required safety margins[35] (see Appendix D, Figure 2). The fact that the remaining runway length at lift-off (430 m, see paragraph 2.3.2) was 211 m more than the calculated distance according to Boeing can be attributed to the fact that the calculations use conservative assumptions.

34 The reason for this is that it is the responsibility of the line organization to determine the way of effective cross-checking, while the S&QA department carried out the investigation.
35 For the investigation the EFB was used to calculate the take-off performance for the correct runway and position, runway 21 position 3, with the same conditions. This resulted in an assumed temperature of 52 degrees Celsius instead of the 65 degrees Celsius used during the incident.

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3.3.2 The runway selection error

In the EFB take-off performance module, both pilots inadvertently selected position 3 on the first page of the runway/identifier selection field. This was take-off position 3 of runway 03 instead of take-off position 3 of runway 21 (see figure 6).

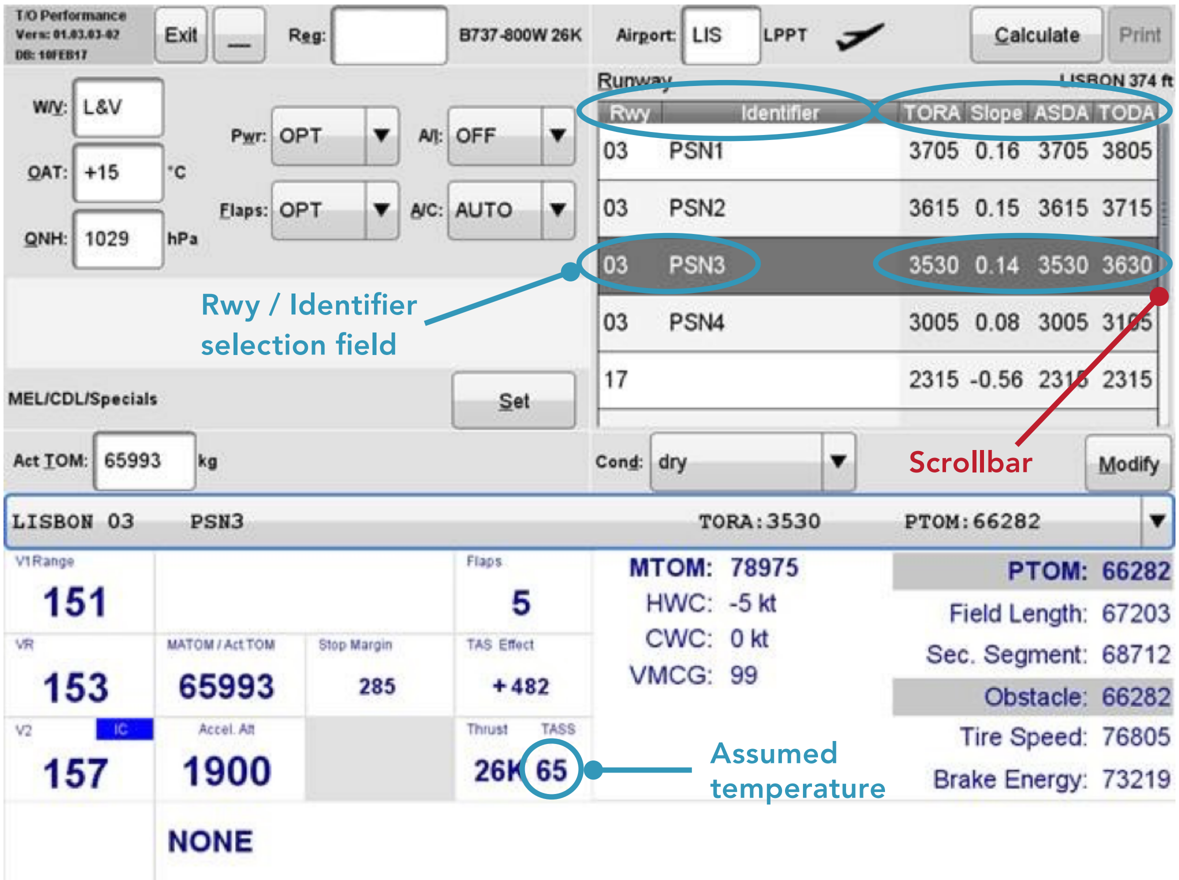

Figure 6: Runway (Rwy) and Identifier selection window before scrolling down. The results on the lower part of the screen only become visible after a selection has been made and the calculate button (top right) has been pressed. As the EFB is controlled by means of a touch screen, scrolling down the rwy/identifier list can also be achieved by moving a finger over the rwy/identifier column.

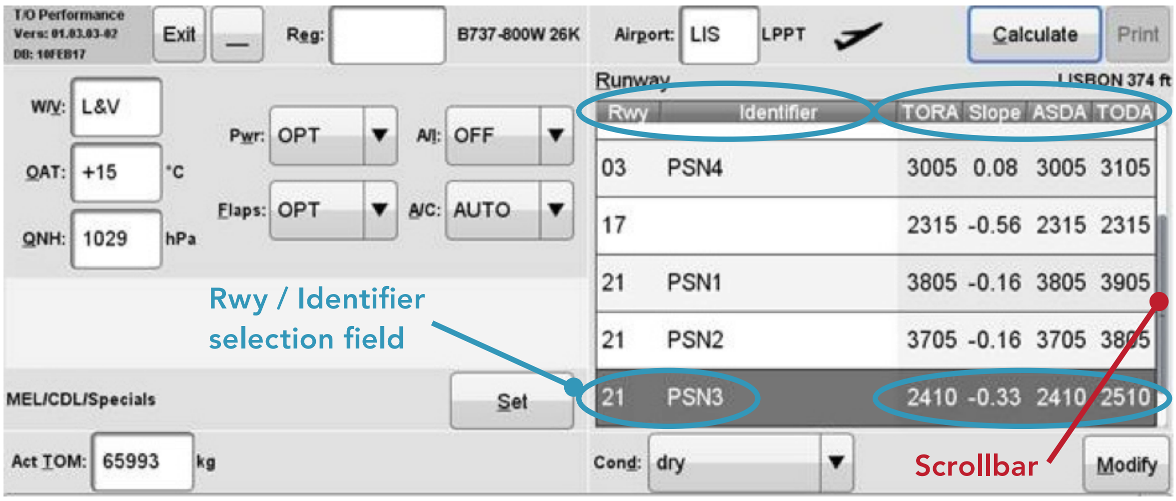

Figure 7: Runway (Rwy) and Identifier selection window after scrolling down.

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Runways often have multiple intersections available for take-off that pilots have to choose from. After selecting the correct runway, the identifier is the final criterion which determines the correct take-off position. The runway-identifier combination is a single selection in the EFB. At most airports the identifier field contains a unique character/ number combination (e.g. the runway intersection designator). Therefore it is likely that, in selecting the runway-identifier combination, the pilots in this case focused on the identifier instead of the runway number. Also, as was stated by one of the pilots, the layout of the selection window draws the focus to the identifier, as it clearly stands out with the blank spaces around the identifier. At Lisbon Airport, the runway identifiers were identical for both runway 03 and runway 21. There were a position 1, 2 and 3 for runway 03 as well as a position 1, 2 and 3 for runway 21. These positions marked different intersections. This made the flight crew susceptible to making a selection error.

The EFB displays the runway numbers and identifiers in a sequential order. As the selection field can only display a maximum of five runway-identifier combinations, the only PSN3 on this page was position 3 of runway 03. The pilots needed to scroll down to view the remaining options. As they saw the first PSN3 in the list, it is likely they thought that the this PSN was the correct one. In addition to this, pilots stated during interviews that runway 21 was rarely in use. Runway 03 was the runway both pilots usually landed and took off from at Lisbon Airport.

3.3.3 Contributing factors to the runway selection error

Take-off position identifiers

The EFB airport data file uses the airport data from the national AIP as source. Therefore the take-off position identifier names in the EFB were also ambiguous. Although ICAO Annex 14 Aerodromes does not provide requirements for the naming of take-off positions, most airports use a logical and unique naming system for aerodrome manoeuvring areas, such as taxiways and ramps.

The fact that the same position numbers are used for take-off positions on different runways in Lisbon increases the chance for errors, as proven by this incident and a previous incident with an Airbus A319.[36]

During this investigation, Lisbon Airport changed the intersection names, see Table 8. The revised take-off intersection names are not conform the recommendations of the ACI Runway Safety Handbook. Furthermore, the revision of the take-off intersection names did not result in a unique naming of the take-off intersection positions. At present, a PSN M is available for runway 03 as well as runway 35. Therefore, there still is a potential for selecting the wrong runway in the take-off performance calculation in the EFB.

36 Air Accident Investigation Branch, *Bulletin 5/2016*, EW/G2015/10/08.

Fatigue
No indications have been found that fatigue has been a contributing factor in the calculation error.

EFB operation and workload
The EFB in use by the operator requires a number of manual data entries and data transfers, not only for operational, but also for administrative purposes. Pilots have to check, amongst others, crew data, flight sector data and aircraft data and make corrections where necessary. Passenger and load information has to be entered for the load and balance calculation. The input of airport and weather data is required for the take-off performance calculations. The data output has to be transferred to the bugcard and the FMC (see Figure 8 for a visualisation of the workflow).

Some information entered in the EFB is already available in the computer systems of the operator (e.g. catering information, flight type, additional equipment), however this information does not get automatically uploaded or transferred. The first officer stated during an interview that he often had to postpone non-essential tasks, which are of an administrative nature, until after take-off because of time pressure. This disrupts the regular workflow for which the EFB has been designed. The captain stated during an interview that because he had only recently been promoted to captain he felt susceptible to time pressure. The turn around time at Lisbon was scheduled to be 35 minutes. During a large portion of this time one member of the flight crew is required to be outside to supervise refuelling of the aircraft. This leaves only a short period of time where both pilots are on the flight deck doing preparations for the following flight.

Although the EFB reduces the number of calculations compared to the manual load and trim procedure (as in the Groningen incident), it still requires a large amount of manual data entries and data transfers. The operator is planning to incorporate a further integration of these functions in the next phase of the EFB, which will decrease the number of data entries.

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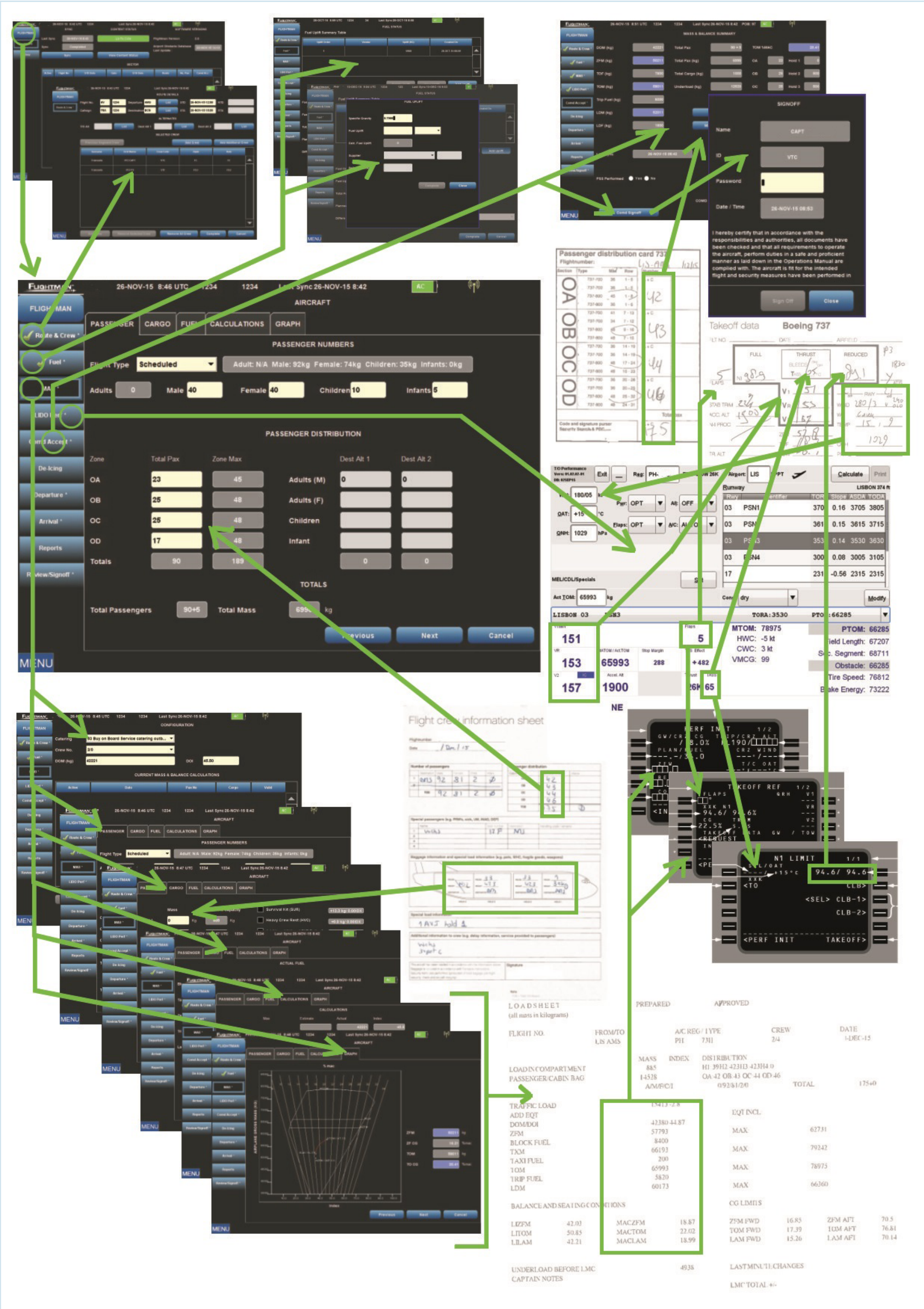

Figure 8: Illustration of the standard EFB flight preparation, weight and balance and take-off performance calculation workflow. Arrows indicate data transfer/entry between different EFB screens, flight documents, FMC and bugcard.

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3.3.4 Error propagation and crosschecking procedures

Crosschecking procedures

The main barrier against errors in the performance calculation is the crosscheck between the outcome of the two independent performance calculations as described in the FCOM and the FCTM, see paragraph 2.4.2. As both pilots made the same input error, the output was the same as well. For that reason the existing crosscheck on the output parameters was not adequate to detect this type of input error.

A small deviation in the input parameters, such as for instance the wind component, can make a substantial difference in the output. According to the flight crew, pilots tend to communicate the input parameters before entering them in the EFB to facilitate crosschecking at the end of the performance calculation. This increases the chance of common input errors being made and as such it reduces the effect of the crosscheck after completion of the performance calculation.

Once the performance calculation is completed, the performance module is closed and the EFB is used for different purposes. During taxi-out, the airport map or departure page of the Lido chart module is usually selected on the EFB. Due to the different software modules, the performance calculation results are not readily available during taxi as the EFB is then showing navigational charts. Therefore, it is not convenient for pilots to open the performance module for reference during taxi.

The EFB take-off performance calculation page incorporates a print button. However, in contrast to its name, the print button only stores the calculated data, it does not send any information to the onboard printer. A printed copy would make the performance calculation data readily available for crosschecking or reference purposes prior to take-off.

During the interviews the pilots mentioned that they have developed their own crosschecking strategy after the incident. This includes paying extra attention to the runway designator during the performance calculation process and a review of the performance data prior to take-off, including the runway/intersection used for the performance calculation. The manuals and procedures do not describe a particular crosscheck to this extent. The fact that pilots stated they developed their own crosschecking strategies when using the EFB is indicative that the existing company crosschecking strategies at the time of the incident were inadequate.

Experience and exposure

The EFB take-off performance calculation is not based on the concept of a balanced field take-off as used in the TL-tables and uses excess runway length for an improved climb performance whenever feasible. The software adjusts the decision speeds to achieve the maximum thrust reduction/maximum assumed temperature to conserve engine life. Under seemingly similar circumstances, the take-off configuration and or decision speeds can differ considerably. As a consequence pilot's awareness and feel for numbers is reduced and a deviation from standard values will not easily be noticed. For instance, the awareness of the relation between the most relevant performance parameter values; TOW, thrust reduction, and TODA, is reduced.

3.3.5 Evaluation and revision of the procedures

According to the operator, these assessments did identify several medium and high risk hazards. As a consequence, several EFB related procedures have been adapted. These procedures have also regularly been amended as the result of reactive feedback from the SMS. However, the hazards identified in the 2013 risk assessments, have not been evaluated since the implementation of the EFB. The risk mitigation measures and adaptations in procedures regarding the EFB were not able to prevent the incident.

3.4 Mixed fleet flying

Study of the schedules of both flight crews preceding the incident flight in paragraphs 1.2.4 and 1.3.4 ruled out mixed flying of the Boeing 737-700 and 737-800 as possible factor in both incidents. The way in which the performance calculation is performed is the same for both variants of the Boeing 737. The resulting weights and speeds differ. However, when assuming imbalanced field take-offs, as in the EFB performance module, it is hard for pilots to develop a feel for the take-off speeds of the aircraft type variant as a small change in the parameters used for the calculation may result in a relatively large change in take-off speeds. It is therefore unlikely that pilots would confuse the take-off speeds of one variant of the Boeing 737-700 for those of the Boeing 737-800.

3.5 Organisational factors

The investigated incidents in Groningen (2014) and Lisbon (2015) give rise to question the operator's risk management policy (paragraph 2.3.3).

No software specific risk assessment

In 2013, a risk analyses of the EFB was performed. At this time it was not clear which software would be used for the performance and weight and balance modules on the EFB (see paragraph 2.4.3). Therefore, hazards related to the ergonomics of these modules could not be assessed. A risk analysis of these hazards was also not carried out after these modules became available.

The layout and as such the ergonomics of the EFB have been a contributing factor in the runway/identifier selection error.

No investigation to the cause of EFB entry errors

From continuous monitoring the operator was aware that data-entry errors occurred regularly. Furthermore, the operator was aware that slips, mixes and typos could still be possible after the introduction of performance and mass and balance calculations on the EFB.[37] However, the operator did not conduct an investigation into the causes of data entry errors in the EFB.

37 Source: Internal investigation report on data entry errors by the operator, 2014

No update back-up procedure
The Groningen incident showed that the manual load and trim procedure was prone to mistakes. This procedure was not changed after the incident because of the implementation of the EFB performance modules. However, the manual load and trim procedure is still in place as back-up in case of a failure of both onboard EFBs. In case the back-up procedure is necessary, flight crew is still susceptible to making the same calculation error that was made during the Groningen incident.

No follow up own recommendation
The follow-up of a data entry investigation into error propagation in 2014 was to emphasize the correct execution of crosschecking procedures during training. The operator did not follow up on the recommendation to review the robustness of crosschecking procedures to disturbances on the flight deck and typos.

Cost benefit of take-off thrust reduction versus increase in safety risks
Operators often choose to perform reduced thrust take-offs in order to conserve engine life and thus reduce maintenance costs. However, the incidents described in this report, and many similar occurrences worldwide, show the increased risks of performing take-offs with reduced thrust. As the variables that determine the cost benefit of reduced thrust take-offs vary with time, there might be times when the safety risks of conducting these take-offs outweigh the decrease in maintenance costs achieved by them.

Sharing of best practices with other operators
As performance incidents occur worldwide, with different aircraft types and in different types of operations, operators can potentially learn from one another by sharing best practices in weight and balance and performance procedures.

3.6 Pilot intervention

When the take-off performance is in doubt and the decision is made to continue the take-off, maximum take-off thrust can be selected by pressing a Take-Off and Go Around (TOGA) switch or advancing the thrust levers to the full forward position for the assumed temperature thrust reduction method (see paragraph 2.4.1).

In both incidents the pilots noticed that the take-off roll was longer than expected, however in neither of the two events the pilots took corrective action. In the Lisbon incident the pilots stated that they realised that there was enough runway length remaining to become safely airborne. As the remaining runway length in the Groningen incident was critical, this take-off will be analysed further.

3.6.1 Pilot awareness in Groningen
During take-off, with the speed above 80 kt, both pilots stated that they noticed that the acceleration was less than expected. Although still below the calculated V_1 decision speed, the captain judged that it was not possible to safely abort the take-off within the remaining runway length. The captain realised correctly that the calculated V_1 speed could not be used as a reference. Boeing afterwards calculated the speed at which the

take-off could have been safely aborted as 122 kt (see Appendix D, Figure 1). This is 15 kt below the V1 speed used by the flight crew.

Although both pilots were aware that something was wrong during the take-off roll, neither pilot selected additional thrust. In line with the FCOM procedures, the captain as pilot monitoring had his hand on the thrust levers during the take-off while the first officer was pilot flying. As a consequence the first officer could only select full thrust by requesting the captain to do so. For the captain as pilot monitoring there might be a reluctance to add thrust, as it interferes with the operation of the first officer as pilot flying. Actions from either pilot would have required clear communication and time. These factors could have contributed to the fact that neither pilot selected additional thrust during take-off.

Reports[38] on similar performance related take-off accidents and incidents show that in the majority of these cases no additional thrust was selected. Only occasionally an early rotation is initiated.

Time critical events such as engine failures and windshear during take-off are regularly trained in the flight simulator. These events are accompanied with clear cues and associated with procedures that have to be executed by heart (memory items). Performance related incidents are not trained in the simulator and the accompanying cues are less obvious. Due to the time critical situation and the lack of associated and trained procedures, it is less likely that pilots take corrective action during a performance related event.

3.7 Further system automation

Further automation, such as take-off performance monitoring systems should be able to reduce the number of take-off performance related incidents (see paragraph 2.4). A performance monitoring system would have prevented the Lisbon incident if the system is able to detect the aircraft's position by GNSS/GPS. A remote automated performance calculation is also not likely to have prevented the occurrence in Lisbon since this was a selection error of the runway and take-off position in use. The current remote automated performance calculations cannot check whether the selected runway and take-off position are correct and will perform a performance calculation based on the input of the flight crew. A selection error of the runway in use would thus still be possible.

On-board weight and balance systems and take-off performance monitoring systems are potentially very effective measures. However, the development of both types of systems is slow, because of the complexity of these systems and the associated costs.

38 See Appendix F: References.

The development of the regulatory framework of both types of systems is also slow. EASA concluded as a result of their risk analysis in 2016 that the priority of developing the regulatory framework in order to reduce the risks of erroneous data entries is low compared to other safety issues, due to the limited amount of fatal injuries (three fatal accidents in 1999-2015). Taking into account the high number of investigated calculation or data input error occurrences as mentioned in paragraph 1.1 and Appendix F, the Dutch Safety Board is of the opinion that these occurrences have a high potential of an accident with many fatalities.

Within the scope of mitigating measures to reduce the risk of erroneous data entries, EASA rates developing the regulatory framework for technical solutions such as OBWBS and TOPMS low due to the lack of cost estimates and uncertain implementation time. However, in the long term, these measures are considered more effective[39] than safety promotion and improvement of the requirements of EFB software (as will be established in MOPS WG-106, see paragraph 2.6.3) and the use of EFBs (see paragraph 2.6.2).

In line with the recommendations from the NLR's study for EASA (paragraph 2.6.4), improvement of the ergonomics of EFB systems and EFB procedures are measures that may reduce the number of take-off performance related incidents in the short-term.

39 See Appendix F: List of relevant safety studies.

4 CONCLUSIONS

Two separate incidents occurred as a result of an insufficient thrust setting for take-off, one in Groningen in 2014 and one in Lisbon in 2015. In both incidents the required safety margins for take-off were not met.

In both incidents, the flight crew did not select additional thrust after realizing the take-off roll was longer than usual. Other investigation reports of performance incidents show that additional thrust is not selected in the majority of the cases. The selection of additional thrust during the take-off roll in performance incidents is not trained in flight simulators. This lack of training makes it less likely that flight crews select additional thrust in a time critical situation, such as a take-off made with an erroneous take-off performance calculation.

Direct causes
In the Groningen incident, the insufficient thrust setting was the consequence of a miscalculation on the bugcard. In the Lisbon incident an incorrect runway and take-off position selection in the EFB performance tool by the flight crew caused the insufficient thrust setting.

The errors could propagate because there were no adequate crosschecks in place to detect the errors. A crosscheck regarding the TOW on the bugcard was lacking in the Groningen incident. A crosscheck that could detect that both pilots were making the same runway selection error was lacking in the Lisbon incident.

Contributing factors
Contributing factors to the calculation error in the Groningen incident were:
- the large number of calculations, data entries and data transfers;
- the lack of guidelines regarding which source should be used for the weight in the take-off performance calculation.
- lack of guidelines regarding the purpose of the bugcard, leading to it being used for a calculation whilst it is meant solely as a reference chart.

Contributing factors of the selection error in the Lisbon incident were:
- the large number of data entries and transfers;
- the ergonomics of the EFB performance module;
- the ambiguous runway take-off position naming system at the airport.

Contributing factor in the error propagation in the Lisbon incident was:

- the large variation in take-off parameters due to the performance optimization of the EFB, which decreases the chance for flight crews to develop a feel for the values of take-off performance parameters.

Underlying causes

The operator did not sufficiently assess the safety barriers and risks associated with the layout and ergonomics of the EFB, because the risk assessments were carried out at a moment that the hardware and software of the EFB were not available yet (2013). After implementation of the EFB, no evaluation was carried out.

EFB processes were not evaluated and an investigation into the causes of data entry errors in EFBs has not been initiated after it became apparent that data entry errors were being made in its operation.

The manual performance procedure was not reviewed after the Groningen incident, although the manual performance procedure is still in place as a back-up in case of failure of both EFBs. A calculation error on the bugcard can thus theoretically still lead to an erroneous performance calculation.

Based on these findings, the DSB is of the opinion that the operator's risk management policy is too reactive and should be more pro-active, in line with the existing Safety Management System principles.

The DSB also wonders if the costs benefits achieved by reduced thrust take-offs outweighs the safety risks introduced by these take-offs as the benefits and drawbacks of take-off thrust reduction may change over time.

Possible preventive measures

Further system automation is considered an effective mitigating measure against the hazards of data-entry and calculation errors. However, development by the industry is slow and EASA has not classified this issue as a high priority due to lack of corroborating statistical information.

For the short term, the focus should be on more guidance and regulation for both the ergonomics of EFB systems and EFB procedures, in line with the conclusions of NLR's study performed for EASA. Besides that, operators can share best practices regarding weight and balance and performance procedures in order the learn from each other, as several reports have shown that performance related incidents occur on many different types of aircraft in many different types of operations.

5 RECOMMENDATIONS

EASA is recommended:

1. To prioritise the development of specifications and the establishment of requirements for Onboard Weight and Balance Systems (RMT.0116).
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 Take-off Performance Monitoring Systems without further delay.

The operator is recommended:

3. To perform periodic risk assessments and to implement mitigating actions on the identified hazards of the complete flight preparation process. These periodic risk assessments should include, but not be limited to:
   - Manual load and balance and performance procedures[40]
   - Take-off or landing data card (bugcard)
   - EFB (hardware, software, procedures and alternatives)
   - Risks of take-off thrust reduction versus the achieved cost benefits

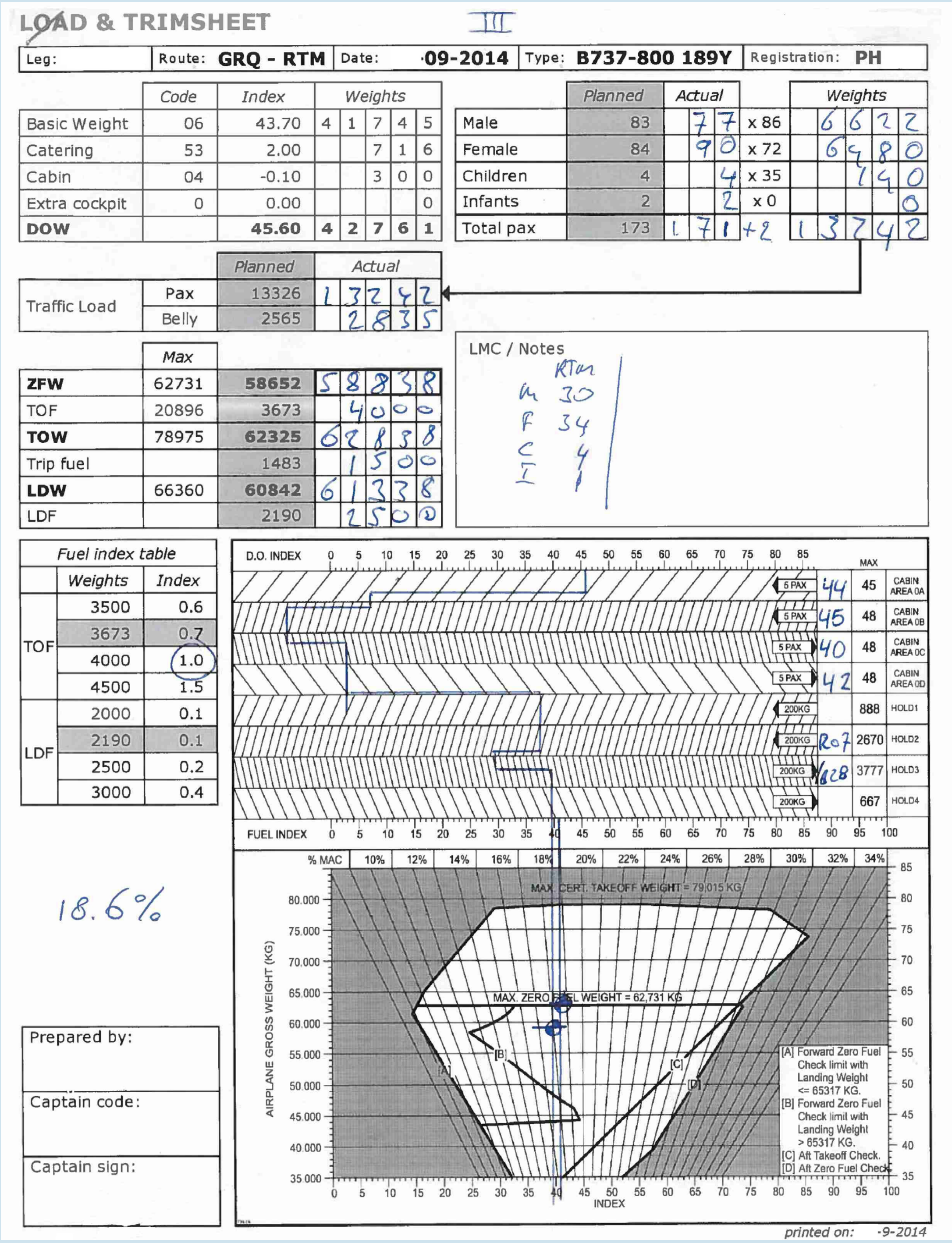
4. To provide simulator training for non-standard situations that require additional thrust during the take-off roll.

The Lisbon Airport management is recommended:

5. To rename the take-off positions, in accordance with the ACI recommendation.

40 Although the manual load and balance procedure and the manual performance calculation procedure have been replaced by the EFB, they still serve as back-up procedures in case the EFB is unserviceable. As such these procedures should be reviewed accordingly.

FLIGHT RELATED DOCUMENTS – GRONINGEN INCIDENT



LOAD & TRIMSHEET III

Leg:	Route: GRQ - RTM	Date: ·09-2014	Type: B737-800 189Y	Registration: PH

	Code	Index	Weights				
Basic Weight	06	43.70	4	1	7	4	5
Catering	53	2.00			7	1	6
Cabin	04	-0.10			3	0	0
Extra cockpit	0	0.00					0
DOW		**45.60**	**4**	**2**	**7**	**6**	**1**

	Planned	Actual		Weights
Male	83	77	x 86	6622
Female	84	90	x 72	6480
Children	4	4	x 35	140
Infants	2	2	x 0	0
Total pax	173	171+2		13242

		Planned	Actual
Traffic Load	Pax	13326	13242
	Belly	2565	2835

	Max		
ZFW	62731	**58652**	58838
TOF	20896	3673	4000
TOW	78975	**62325**	62838
Trip fuel		1483	1500
LDW	66360	**60842**	61338
LDF		2190	2500

LMC / Notes
RTM
M 30
F 34
C 4
I 1

Fuel index table

	Weights	Index
TOF	3500	0.6
	3673	0.7
	4000	1.0
	4500	1.5
LDF	2000	0.1
	2190	0.1
	2500	0.2
	3000	0.4

18.6%

Prepared by:

Captain code:

Captain sign:

printed on: -9-2014

Figure 1: Appendix A - LTS Groningen.

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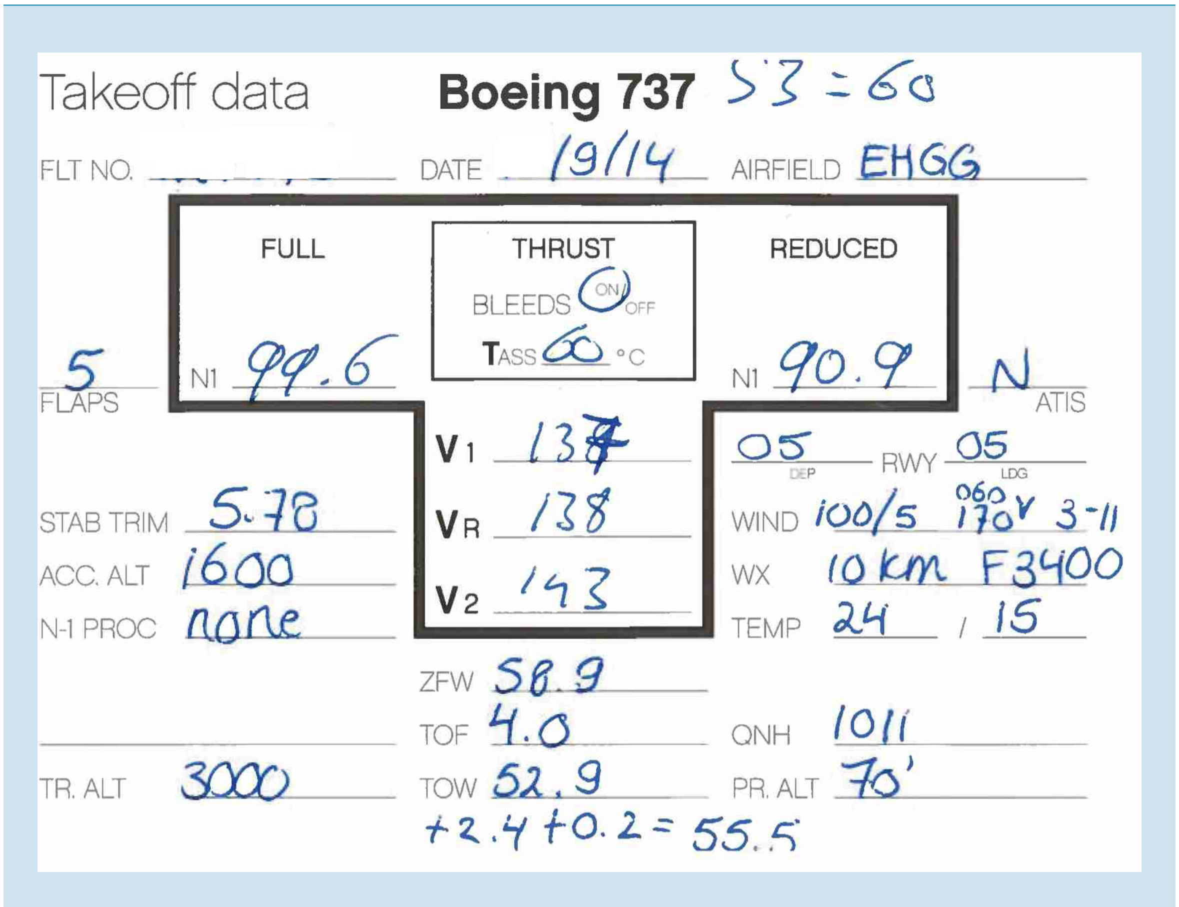

Takeoff data
Boeing 737 53=60
FLT NO.
DATE 19/14
AIRFIELD EHGG

FULL
THRUST
BLEEDS ON OFF
TASS 60 °C
REDUCED

5
FLAPS
N1 99.6
N1 90.9
N
ATIS

V1 138
VR 138
V2 143

05 DEP RWY 05 LDG

STAB TRIM 5.78
ACC. ALT 1600
N-1 PROC none

WIND 100/5 060 170V 3-11
WX 10 km F3400
TEMP 24 / 15

ZFW 58.9
TOF 4.0
TOW 52.9
+2.4+0.2=55.5

QNH 1011
PR. ALT 70'

TR. ALT 3000

Figure 2: Appendix A - Take-off data card ('bugcard') Groningen.

PERFORMANCE MANUAL

ELEVATION 17 FT RUNWAY 05 EHGG

*** FLAPS 05 *** **AIR COND OFF** ANTI-ICE OFF GRONINGEN GRQ
WINGLET PERFORMANCE THE NETHERLANDS
737-800 CFM56-7B26 DATED 16-APR-2013

MAXIMUM BRAKE RELEASE WEIGHT-KG AND LIMIT CODE

OAT C	WIND COMPONENT IN KNOTS (MINUS DENOTES TAILWIND) -15	-10	-5	0	10	20	CLIMB LIMIT
-12	75700F	78500F	81300F	84200F	86100*	86200F	86200
-8	75300F	78000F	80800F	83700F	85700F	86200F	86200
-4	74800F	77500F	80200F	83100F	85100F	86200F	86200
0	74300F	77000F	79700F	82500F	84500F	86200F	86200
4	73800F	76500F	79200F	82000F	83900F	85900F	86200
8	73300F	76000F	78700F	81400F	83400F	85300F	86200
12	72800F	75500F	78100F	80900F	82800F	84700F	86200
16	72300F	75000F	77600F	80400F	82200F	84200F	86200
20	71800F	74500F	77100F	79800F	81700F	83600F	86200
22	71600F	74300F	76900F	79600F	81400F	83300F	86200
24	71300F	74000F	76600F	79300F	81200F	83000F	86200
26	71100F	73800F	76400F	79100F	80900F	82800F	86200
28	70900F	73600F	76200F	78800F	80600F	82500F	86200
30	70600F	73300F	75900F	78500F	80300F	82200F	86200
32	69800F	72500F	75100F	77700F	79500F	81300F	86100
34	69000F	71600F	74300F	76800F	78600F	80400F	84700
36	68200F	70800F	73500F	76000F	77800F	79600F	83500
38	67500F	70000F	72600F	75200F	76900F	78700F	82100
40	66600F	69200F	71700F	74300F	76000F	77700*	80700
42	65800F	68300F	70800F	73400F	75100F	76700*	79400
44	65000F	67400F	69900F	72500F	74100*	75600*	78000
46	64200F	66600F	69100F	71600*	73100*	74600*	76700
48	63400F	65800F	68200F	70600*	72100*	73600*	75300
50	62600F	64900F	67300F	69600*	71100*	72400*	74000
52	61900F	64200F	66500F	68700*	70200*	71400*	72700
54	61200F	63400F	65700F	67800*	69200*	70300*	71500
56A	60500F	62700F	64900*	67000*	68300*	69200*	70400
58A	59800F	62000F	64100*	66100*	67400*	68300*	69300
60A	59100F	61300F	63400*	65300*	66400*	67300*	68200
BELOW REF: -KG/MB	70	73	71	74	76	78	80

ENGINE FAILURE PROCEDURE

NONE

***** APPLY CLEARWAY AND STOPWAY V1 ADJUSTMENTS TO FMC COMPUTED V1 SPEED *****

CLEARWAY MINUS STOPWAY FOR V1 CORRECTIONS = 60 M
MINIMUM FLAP RETRACTION ALTITUDE IS 1600 FT

TORA IS 2500 M , TODA IS 2560 M , ASDA IS 2500 M
RUNWAY SLOPES ARE -0.01 PERCENT FOR TODA AND -0.01 PERCENT FOR ASDA

RUNWAY	HT	DIST	OFFSET	HT	DIST	OFFSET	HT	DIST	OFFSET
05	1	30	0	3	60	0	13	310	0

Figure 3: Appendix A -TL-table runway 05 (full length) Groningen.

PERFORMANCE MANUAL

ELEVATION 17 FT RUNWAY 05-S3 EHGG

*** FLAPS 05 *** **AIR COND OFF** ANTI-ICE OFF GRONINGEN GRQ
WINGLET PERFORMANCE THE NETHERLANDS
737-800 CFM56-7B26 DATED 16-APR-2013

MAXIMUM BRAKE RELEASE WEIGHT-KG AND LIMIT CODE

OAT C	WIND COMPONENT IN KNOTS (MINUS DENOTES TAILWIND) -15	-10	-5	0	10	20	CLIMB LIMIT
-12	62300F	65100F	68100F	71100F	73200F	75200F	86200
-8	61900F	64700F	67600F	70600F	72600F	74600F	86200
-4	61400F	64200F	67100F	70000F	72100F	74100F	86200
0	61000F	63700F	66600F	69500F	71500F	73600F	86200
4	60600F	63300F	66100F	69000F	71000F	73000F	86200
8	60200F	62800F	65600F	68500F	70500F	72500F	86200
12	59700F	62400F	65100F	68000F	70000F	72000F	86200
16	59300F	62000F	64700F	67500F	69400F	71400F	86200
20	58900F	61500F	64200F	67000F	68900F	70900F	86200
22	58700F	61300F	64000F	66800F	68700F	70600F	86200
24	58500F	61100F	63800F	66500F	68400F	70400F	86200
26	58300F	60900F	63600F	66300F	68200F	70100F	86200
28	58100F	60700F	63300F	66100F	67900F	69900F	86200
30	57900F	60500F	63100F	65800F	67700F	69600F	86200
32	57300F	59800F	62400F	65100F	66900F	68800F	86100
34	56700F	59200F	61800F	64400F	66200F	68100F	84700
36	56100F	58600F	61100F	63700F	65500F	67300F	83500
38	55500F	57900F	60500F	63000F	64700F	66600F	82100
40	54900F	57300F	59800F	62300F	64000F	65800F	80700
42	54200F	56600F	59100F	61600F	63200F	65000F	79400
44	53600F	56000F	58400F	60800F	62500F	64200F	78000
46	53000F	55300F	57700F	60100F	61800F	63500F	76700
48	52400F	54700F	57000F	59400F	61100F	62700F	75300
50	51700F	54000F	56300F	58700F	60300F	62000F	74000
52	51100F	53400F	55700F	58000F	59600F	61300F	72700
54	50600F	52800F	55000F	57400F	58900F	60600F	71500
56A	50000F	52200F	54400F	56700F	58300F	59900F	70400
58A	49500F	51700F	53900F	56100F	57700F	59200F	69300
60A	49000F	51100F	53300F	55500F	57100F	58600F	68200
BELOW REF: -KG/MB	55	58	60	65	67	70	80

ENGINE FAILURE PROCEDURE
NONE

***** APPLY CLEARWAY AND STOPWAY V1 ADJUSTMENTS TO FMC COMPUTED V1 SPEED *****

CLEARWAY MINUS STOPWAY FOR V1 CORRECTIONS = 60 M
MINIMUM FLAP RETRACTION ALTITUDE IS 1600 FT

TORA IS 1800 M , TODA IS 1860 M , ASDA IS 1800 M
RUNWAY SLOPES ARE -0.02 PERCENT FOR TODA AND -0.02 PERCENT FOR ASDA

RUNWAY	HT	DIST	OFFSET	HT	DIST	OFFSET	HT	DIST	OFFSET
05-S3	1	30	0	3	60	0	13	310	0

Figure 4: Appendix A -TL-table runway 05 (intersection S3) Groningen.

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MANUALS

Operations Manual - Part A | 8.1 FLIGHT PREPARATION INSTRUCTIONS
8.1.12 List of Documents, Forms and Additional Information to be carried

14. TAKEOFF AND LANDING DATA CARD ('BUGCARD')

For each flight a Takeoff and Landing data card shall be completed. The minimum required information, that shall be filled out is enclosed in the frames "T" for takeoff and "L" for landing. For takeoff this information includes, the N1 settings, V-Speeds, Assumed temperature and bleed configuration. For landing, this information includes, landing weight, flaps setting, Vref speed, final approach speed, outer marker crossing altitude (or equivalent), approach minimums, touchdown zone elevation and the missed approach altitude.

Although not required, it is strongly recommended to complete all information as contained on the Takeoff and Landing data card.

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Figure 1: Appendix B - OM-A 8.1.12-14

Normal Procedures - Introduction

737 Flight Crew Operations Manual

Crosschecking

Crosschecking is an essential safeguard to prevent and to detect data entry or handling errors. Procedures to reduce errors shall be carried out consistently at all times. Last minute changes and disruptions shall be recognized as contributing factors, that increases the probability of errors. These conditions require awareness and involvement of both pilots to detect and recognize any possible errors. Any discrepancies shall be promptly dealt with.

Crosschecking procedures are an integral part of the Normal Procedures. Independent of applicable procedures or phase of flight a general principle of effective crosschecking is that performance and configuration parameters are always verified by the other pilot against related independent systems, indicators and relevant flight briefing information, for example:

- For ZFW; crosscheck between flight plan, mass and balance calculations and CDU.
- For V-Speeds; crosscheck between performance calculations and CDU
- For Flaps setting; crosscheck between performance calculations, CDU, flap lever and flap position indicators.

Figure 2: Appendix B - FCOM1 NP.11.4.

Crosschecking policy

Crosschecking is an essential safeguard to prevent and to detect data entry or handling errors. Procedures to reduce errors shall be carried out consistently at all times. Last minute changes and disruptions shall be recognized as contributing factors, that increases the probability of errors. These conditions require awareness and involvement of both pilots to detect/recognize any possible errors. Any discrepancies shall be promptly dealt with.

Crosschecking procedures are an integral part of the SOP. Independent of applicable procedures and/or phase of flight general principles of effective crosschecking procedures are:

- Always verify output parameters against related independent systems, indicators and relevant flight briefing information. Use all resources available, which are (but are not limited to):
  - For ZFW, crosscheck between flight plan, EFB calculations and FMC;
  - For V-Speeds, crosscheck between EFB calculations and FMC;

1.2 | 737 NG FCTM | February 01, 2014

Figure 3: Appendix B - FCTM 1.2 General Information.

Normal Procedures - Amplified Procedures

737 Flight Crew Operations Manual

PERF INIT page:

Enter the ZFW.

Verify that the FUEL on the CDU, the dispatch papers, and the fuel quantity indicators agree.

If refueling is not complete, enter the PLAN takeoff fuel as needed.

Verify that the fuel is sufficient for flight.

Verify that the gross weight and cruise CG (GW/CRZ CG) on the CDU and the dispatch papers agree.

March 27, 2014 | NP.21.5

Figure 4: Appendix B - FCOM1 NP.21.5.

ACMS TAKE-OFF DATA GRAPHS

Groningen incident

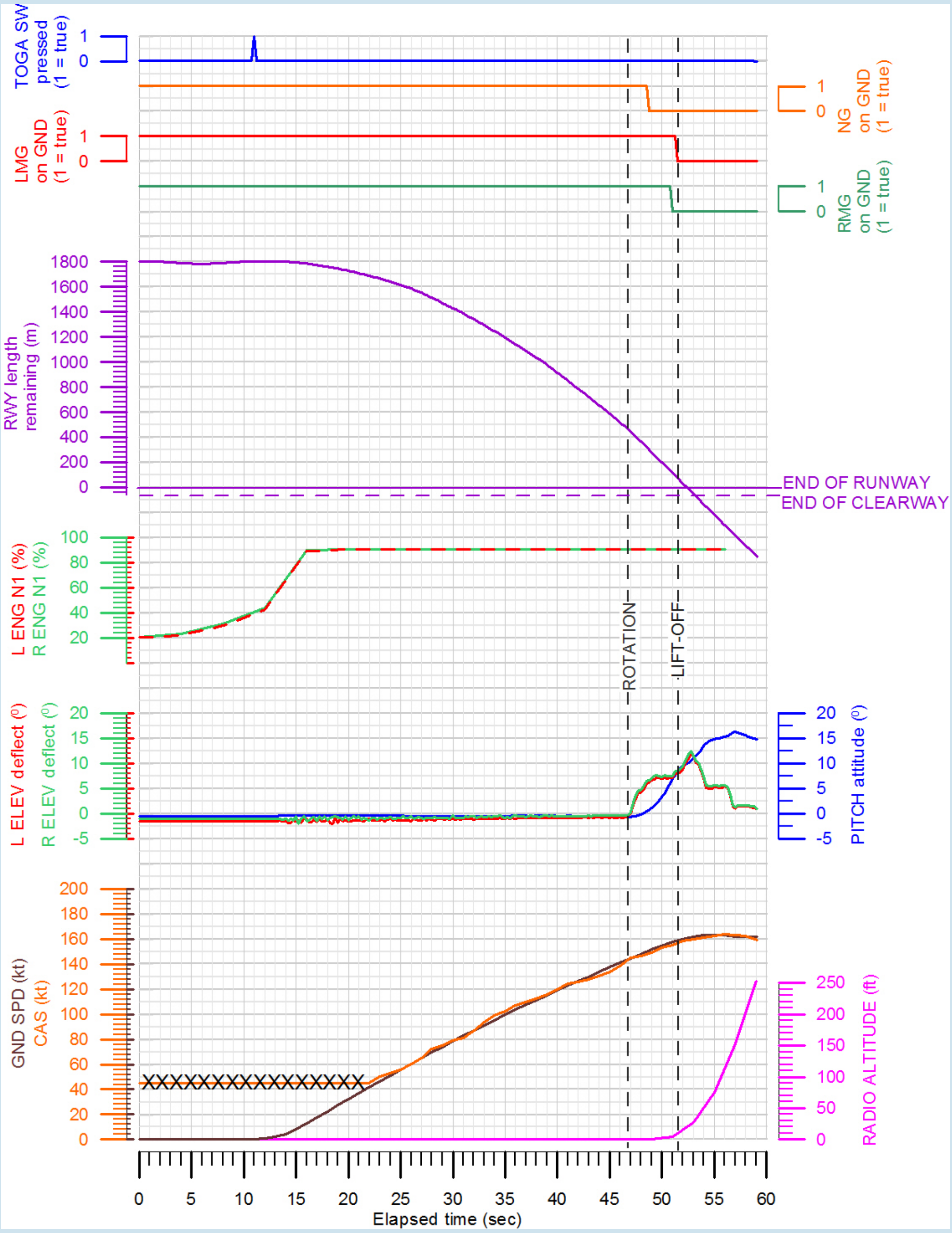

Figure 1: Appendix C.

Lisbon incident

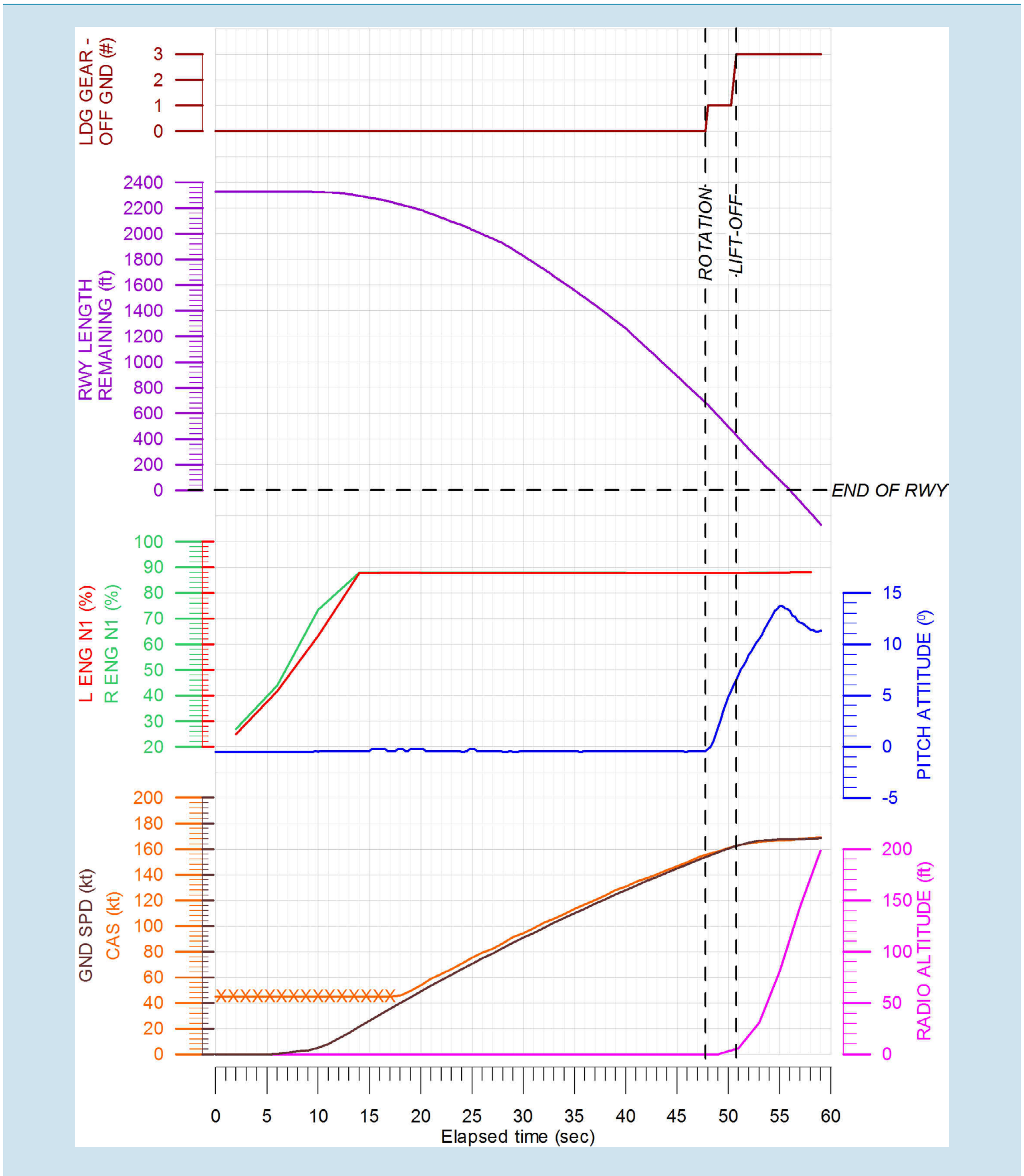

Figure 2: Appendix C.

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TAKE-OFF DISTANCES AND SPEEDS

Calculations performed by Boeing

Groningen incident	Calculated distances (for actual conditions)	Safety margin '- ' = a negative margin
ASDR	2,271 m	- 471 m
ASDA	1,800 m	
TORR – legally required (all engines, factored by 115%)	2,148 m	- 348 m
TORR – legally required (engine failure, unfactored)	2,083 m	- 283 m
TORR – uncorrected (all engines, unfactored)	1,868 m	- 68 m
TORA	1,800 m	
TODR – legally required (all engines, factored by 115%)	2,339 m	- 479 m
TODR – legally required (engine failure, unfactored)	2,311 m	- 451 m
TODR – uncorrected (all engines, unfactored)	2,033 m	- 173 m
TODA	1,860 m	
	V_1 – speeds (considering T/O abort)	Speed margin '- ' = a negative margin
Calculated V_1	137 kt	
Corrected V_1	122 kt	- 15 kt

Figure 1: Appendix D - Take-off distances, speeds and safety margins Groningen.

Lisbon incident	Calculated distances (for actual conditions)	Safety margin '- ' = a negative margin
ASDR	2,900 m	- 490 m
ASDA	2,410 m	
TORR – legally required (all engines, factored by 115%)	2,519 m	- 109 m
TORR – legally required (engine failure, unfactored)	2,416 m	- 6 m
TORR – uncorrected (all engines, unfactored)	2,191 m	+ 219 m
TORA	2,410 m	
TODR – legally required (all engines, factored by 115%)	2,898 m	- 488 m
TODR – legally required (engine failure, unfactored)	2,858 m	- 448 m
TODR – uncorrected (all engines, unfactored)	2,520 m	- 10 m
TODA	2,510 m	
	V_1 – speeds (considering T/O abort)	Speed margin '- ' = a negative margin
Calculated V_1	151 kt	
Corrected V_1	138 kt	- 12 kt

Figure 2: Appendix D - Take-off distances, speeds and safety margins Lisbon.

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AUTOMATION

Centralised automated systems

Centralised automated systems are in use by various operators. The centralised systems described below, significantly reduce manual data entries and calculations, thus reducing the pilot's workload.[41] Furthermore, these systems perform automated gross error checks of values entered and computed.

Automated load and balance systems

The required weight and centre of gravity information is provided by a centralised load planning system without interaction of the flight crew. These systems provide automated crosschecks against input and output errors. The task left to the pilots is to perform a general crosscheck against the pre-flight data to detect errors. Other terms used for automated load and balance systems are centralised load planning systems or computerised load-sheets.

Automated performance calculations

Based on the weight, aircraft configuration, runway and environmental data provided by flight crew, this system centrally calculates the performance and compares the input against stored data. The results of the performance calculation are then sent to the flight crew using datalink technology. An automated performance calculation system provides protection against many different types of calculation errors. Input errors are still possible, but through its built-in crosschecking capabilities the system warns the flight crew for many gross errors.

On-board systems

Overview

The aviation industry is continuously searching for systems to reduce the number of take-off related incidents and accidents. Investigation reports have proposed various technical solutions as barriers against performance related errors. These systems are either intended to catch input and output errors by built-in crosschecks in take-off performance related aircraft systems or ultimately by monitoring the actual take-off performance:

41 See Appendix F: References.

1. On-board 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) for the weight and balance values used in the performance data process.

2. Inhibition of the Gross Weight entry field in the FMC:
   The entry field for the Gross Weight of the aircraft is inhibited in the FMC of the aircraft. This prevents mistakenly entering the ZFW of the aircraft in the Gross Weight entry field in the FMC. The Gross Weight is then automatically calculated by the FMS by adding up the entered ZFW and the mass of the fuel on board. This function was installed in the aircraft involved in both incidents.

3. Automated crosschecks between aircraft take-off performance related systems for:
   a. Actual versus planned take-off position
   b. Actual versus planned TOW
   c. Correlation of data in FMS, performance calculation and weight and balance calculation.

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

Boeing
At present, the Boeing aircraft systems incorporate gross error checks on FMC inputs and configuration checks.

For the more recent aircraft types (Boeing 777 and 787) an EFB with an Onboard Performance Tool (OPT) is available. Flight crews can automatically copy data from the airplane directly into the OPT from the FMC, thereby avoiding the need to manually enter those parameters. Similarly, calculated take-off performance data can be transferred to the FMC from the OPT. Boeing is investigating providing similar capabilities for portable EFB solutions to reduce the amount of manually-entered data on many of their production aircraft.

The Boeing 777 is equipped with a weight and balance system to validate the stabilizer trim green band calculation. This system utilises a pressure transducer located on the nose gear for checking the balance of the airplane. This transducer was not designed to be at an accuracy level to allow it to provide weight inputs. Boeing is currently studying the feasibility of detecting major weight input errors on the 777.

At present Boeing does not provide an on-board weight and balance system or a take-off performance monitoring system for Boeing 737 aircraft.

Airbus
As part of their Future System Evolution, Airbus has implemented and is developing multiple so-called Take Off Securing (TOS) and Take-Off Monitoring (TOM) functions. The TOS functions that are already available are related to gross inconsistency checks on take-off parameter inputs to the FMC, such as ZFW and take-off speeds, or a crosscheck on the trim settings and flap settings. More complex functions, linked to active monitoring of the take-off, are still under study.

Concluding
Airbus has incorporated some automated crosschecks in the FMS. More complex functions, such as take-off performance monitoring systems are under study but not foreseeable in the near future. Boeing has not been working on a take-off performance monitoring system recently. A system that validates the stabilizer green band calculation, using weight and CG inputs, is available for the B777 and B787 aircraft. However, the weight sensing capability of this system is not designed to be at an accuracy level that would allow a check of the weight input in the FMC.

APPENDIX F

REFERENCES

Worldwide numerous take-off incidents and accidents have happened due to calculation or data input errors. Several investigation and research reports have been published regarding take-off performance related incidents. The Dutch Safety Board has also investigated this type of incident; *Take-off with insufficient engine thrust, Boeing 777-300ER, Amsterdam Airport Schiphol, 7 July 2013*, published in its first Quarterly Aviation Report of 2016.

These reports focus on two general area's to reduce calculation and input errors:

- Improvement of flight preparation and crosschecking procedures.
- Implementation of system automation with built-in crosschecking facilities.

An investigation of the Australian Transport Safety Bureau in 2011 analysed 31 significant performance occurrences worldwide between 1989 and 2009. It concludes that performance errors occur worldwide and with different types of aircraft conducting different types of operations. An internal report of the safety department of the operator mentioned in this report analysed 50 data entry errors in the time span of one year and ten months. This report also states that there is underreporting of data entry errors by flight crews and that not all data entry errors can be found using flight data monitoring.

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APPENDIX G

DRAFT REPORT

A draft version of this report has been presented to the parties involved in accordance with the Dutch Safety Board Act. These parties have been requested to check the report for any factual inaccuracies. The report has been presented to the following persons and organisations:

- Operator;
- Flight crews of the Groningen and Lisbon incidents;
- Human Environment and Transport Inspectorate (IL en T);
- National Transportation Safety Board (NTSB);
- The Boeing Company;
- European Aviation Safety Agency (EASA);
- Gabinete de Prevenção e Investigação de Acidentes com Aeronaves (GPIAA);
- Lisbon Airport;
- Bundesstelle für Flugunfalluntersuchung (BFU).

The Dutch Safety Board received a response from all of these parties with the exception of the BFU.

The Board has incorporated corrections of factual inaccuracies, additional details as well as editorial comments, where relevant. The relevant passages were amended accordingly in the final report.

The Board replied to the responses that were not included in the report and included them in the table below (both the original responses and the Board its reply). The page numbers listed in the table refer to the numbering of the draft report and no longer necessarily correspond to the numbering in the final report.

Party	Page number	Text in draft report	Response of party	Board's reply
Operator	9	.. to include the bugcard in the crosscheck….	The use of the bugcard for performance calculations was not required and therefore such a recommendation would not make sense.	The use of the bugcard for performance calculations is not mandatory. However, flight crew stated they were trained to use the take-off weight on the bugcard as source for the performance calculations. The take-off weight on the bugcard therefore becomes an important value.
Operator	9	Sentence 'Besides that, the operator …… made in the operation' is incorrect.	The text suggests that we are aware of an issue regarding data entry errors in the EFB without proper follow up. Contrary to that we monitor and continue to monitor data entry errors regardless where they are made.	The operator was aware that data entry errors were being made on EFBs. This became apparent because of the operator its safety management system. The precise causes of these EFB entry errors did not become subject of an investigation report (see paragraphs 2.4.3 and 3.5).
Operator	44	Same sentence is in the conclusion page 44 regelnr 1. This issue is not addressed in the report.	The text suggests that we are aware of an issue regarding data entry errors in the EFB without proper follow up. Contrary to that we monitor and continue to monitor data entry errors regardless where they are made.	The operator was aware that data entry errors were being made on EFBs. This became apparent because of the operator its safety management system. The precise causes of these EFB entry errors did not become subject of an investigation report (see paragraphs 2.4.3 and 3.5).
Operator		In the factual description of the LIS incident the focus is very much on the performance calculation error. There is hardly no attention for the hazardous runway lay out.	The runway layout at LIS did not comply with the Airport Council Runway Safety Handbook. The lay out is considered as an important contributing factor for this incident.	The description of the ambiguous naming of take-off positions has been expended in the factual chapter of the report. Some text concerning this topic has also been moved from the analysis chapter to the factual chapter. Nevertheless, the investigation focussed on the performance calculation error since a multitude of take-off performance error investigations have shown that these occurences can have a wide variety of contributing causes. Amongst others, these include calculation errors, selection errors and input errors. A commonality in take-off performance occurences is that the error is not caught in the remaining checks of the performance calculation. This shows the importance of a robust take-off performance calculation procedure.

Party	Page number	Text in draft report	Response of party	Board's reply
Operator	43	Same comment for the conclusion.		The ambiguous runway take-off position naming system at Lisbon is stated as a contributing factor in the conclusions. The naming of take-off positions is also the subject of a recommendation.
Operator	33	The operator has not imposed a crosschecking procedure on the bugcard.	In order to be consistent with other text. Here should be added that the procedure is not in use anymore. Actually the sentence has no relevance and can be taken out completely.	The manual performance procedure is still in place as a back-up procedure in case of EFB failure. This is stated in the operator's Operating Manual - A and is described in paragraph 2.4.2 of the report. As flight crews may be trained to use the TOW listed on the bugcard as source for the performance calculation, the DSB is of the opinion that this sentence has relevance. A lack of guidelines regarding the purpose of the bugcard leading to it being used for a calculation, whilst it is meant solely as a reference chart, is also mentioned in the conclusions of the report.
Operator	34	Sentence: 'however the report doesn't mention how effective crosschecking can be achieved' should be deleted. As it is written now it considers to be a shortcoming of the internal investigation.	The sentence should be deleted since this is not the purpose of an incident investigation. It is up to the line organization to determine the way of effective crosschecking.	A footnote has been added to describe that within the operator its organisational structure, it is not the task of the S&QA department to determine a method of effective crosschecking. It is therefore not considered a shortcoming of the internal investigation. However, the DSB is of the opinion that a method of effective crosschecking should have been researched by the operator, be it by another department.

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