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INVESTIGATION REPORT

Serious incident on 22 May 2015
at Paris - Charles-de-Gaulle
to Boeing 777-F
registered **F-GUOC**
operated by **Air France**

BEA
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SPECIAL FOREWORD TO ENGLISH EDITION

This is a courtesy translation by the BEA of the Final Report on the Safety Investigation published in December 2018. As accurate as the translation may be, the original text in French is the work of reference.

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Glossary

AFM	Aircraft Flight Manual
AMC	Acceptable Means of Compliance
AOC	Air Operator Certificate
AP	AutoPilot
ARMS	Aviation Risk Management Solutions
ARO	Authority Requirement for Air Operations
ASDA	Acceleration Stop Distance Available
ASR	Air Safety Report
ATSB	Australian Transport Safety Bureau
CAP	Public air traffic (Circulation Aérienne Publique)
CAS	Calibrated Air Speed
CASIA	Civil Aviation Safety Investigation Authorities
CDU	Control Display Unit
CRM	Crew Resource Management
CVR	Cockpit Voice Recorder
DAC	Civil aviation directorates (Directions de l'Aviation Civile)
DCS	Safety oversight directorate (Direction du Contrôle de la Sécurité)
DGAC	French civil aviation authority (Direction Générale de l'Aviation Civile)
DOW	Dry Operating Weight
DSAC	Civil aviation safety directorate, France (Direction de la Sécurité de l'Aviation Civile)
DSB	Dutch Safety Board
EASA	European Aviation Safety Agency (Europe)
ECR	European Central Repository
EFB	Electronic Flight Bag
EICAS	Engine Indication and Crew Alerting System
EUROCAE	EURopean Organisation for Civil Aviation Equipment
FAA	Federal Aviation Administration
FCOM	Flight Crew Operations Manual
FCTM	Flight Crew Training Manual
FDM	Flight Data Monitoring

FDR	Flight Data Recorder
FL	Flight Level
FMC	Flight Management Computer
FMS	Flight Management System
FOB	Fuel On Board
FOI	Flight Operation Inspector
FORDEC	Facts Options Risks Decide Execute Check
FSO	Flight Safety Officer
ft	Feet
GM	Guidance Material
GPS	Global Positioning System
GW / GR WT	Gross Weight
kt	Knot
LEF	Training Manual (Livret d'Entraînement et de Formation)
LINTOP	Lido INtegrated Takeoff Performance tool
LOSA	Line Operations Safety Audit
MCT	Technical Inspection Manual (Manuel de Contrôle Technique)
MMS	Minimum Maneuvering Speed
MOPS	Minimum Operational Performance Standards
MTOW	Maximum Take-Off Weight
NASA	National Aeronautics and Space Administration
NOTAM	Notice To AirMen
NPA	Notice of Proposed Amendment
NTSB	National Transportation Safety Board (USA)
OBWBS	On-Board Weight and Balance Systems
OFP	Operational Flight Plan
OPT	On-board Performance Tool
ORO	Organisation Requirement for Air Operators
PF	Pilot Flying
PFD	Primary Flight Display
PIA	Preliminary Impact Assessment
PLD	PayLoaD
PLI	Pitch Limit Indicator

PM	Pilot Monitoring
QAR	Quick Access Recorder
QRH	Quick Reference Handbook
RMT	RuleMaking Task
SIB	Safety Information Bulletin
SMS	Safety Management System
SRM	Safety Risk Management (EASA Safety Risk Management Process)
SSP	State Safety Program
TAIC	Transport Accident Investigation Commission (New Zealand)
TODA	Take-Off Distance Available
TOGA	Take-Off Go-Around
TOM	Take-Off Monitoring
TOPMS	Take-Off Performance Monitoring System
TORA	Take-Off Runway Available
TOS	Take-Off Securing
TOW	Take-Off Weight
TR	Type Rating
TRE	Type Rating Examiner
TSB	Transportation Safety Board (Canada)
TSP	TailStrike Protection
UTC	Coordinated Universal Time
VR	Rotation speed (Vitesse de Rotation)
WG	Working Group
ZFW	Zero Fuel Weight

Synopsis

Time	At 10:25[1]
Operator	Air France
Type of flight	Cargo flight
Persons on board	Captain (PM), Co-pilot (PF), two Relief Pilots
Consequences and damage	None

[1] Except where otherwise indicated, the times in this report are in UTC.

Calculation of take-off parameters with an erroneous weight, take-off at low speed, opposite threshold flown over at low height

The Boeing 777-F took off at low speed and the TailStrike Protection (TSP) of the aeroplane was activated. The aeroplane did not gain altitude. The crew then applied full thrust. The aeroplane flew over the opposite threshold at a height of approximately 170 ft and continued to climb. During the climb, the crew discussed the causes of the incident and realized they had made a mistake of 100 tonnes in the weight used for the calculation of the take-off performance parameters. The crew continued the flight to destination without any further incident.

The investigation showed the lack of robustness of the operator's procedures and the heterogeneity of the weight data manipulated. These elements contributed to the error of 100 tonnes and to the ineffectiveness of the checks of the weight values used, in particular they did not lead the crew to use the known orders of magnitude.

The crew was not warned by the aircraft systems about the gross difference of 100 tonnes between the weight entered in the EFB to calculate performances and the weight calculated by the FMS. Nor was the crew warned of the loss of protection against the entry of speeds which were too low. A FMS message was displayed to inform the crew that the FMS could not compute reference speeds but this did not enable the crew to detect inconsistencies in the entered data.

For more than 15 years, several international studies and numerous investigation reports have studied the question of the use of erroneous parameters at take-off. The findings from these works converge to highlight the limitations of operational barriers and to promote technical solutions such as On-Board Weight and Balance Systems (OBWBS), data discrepancy detection and warning systems during data entry and Take-Off Performance Monitoring Systems (TOPMS).

The main civil aviation authorities around the world have taken different approaches to these areas of improvement. The FAA, EASA and Transports Canada[2] initiated various working groups to study the benefits, feasibility and possible standardization of these systems. However, up to the publication of this report, civil aviation authorities have not been able to significantly bring their influence to bear on the availability of the most effective technical solutions. Based on the safety benefits assumed to be achievable in the short term, EASA, for example, until the serious incident of F-GUOC and again thereafter, prioritized the reinforcement of operational barriers, thus targeting Competent Authorities, operators and training organisations. It was assumed by EASA that these actions would be supplemented by the technical progress achieved by the industry. For all that, EASA has not yet completed the review of new technical systems actually developed by the industry and has therefore not been able to encourage their deployment, at least on the most exposed aircraft types.

[2]Canadian Department of Transport.

This is why, as for most aircraft operated for commercial air transport, the Boeing 777 registered F-GUOC was not and still is not equipped with effective systems to prevent the use of erroneous parameters at take-off.

As a result, the BEA has issued several safety recommendations to Air France, the DGAC, Boeing and EASA. These concern in particular:

- data entry procedures and associated weight data media;
- warnings and protections related to the use of erroneous speeds on Boeing 777; and
- more generally, technical systems to be developed and/or implemented on the most exposed aircraft types.

ORGANISATION OF THE INVESTIGATION

The BEA was notified of the incident the same day and initiated a safety investigation.

The investigation team interviewed the crew. It worked with Air France, DSAC, DSB, EASA, Boeing and NTSB.

This report contains ten safety recommendations.

1 - FACTUAL INFORMATION

1.1 History of the flight

Note: the following elements are based on data retrieved from the Quick Access Recorder (QAR), statements from the flight crew and working meetings with the operator and the manufacturer. The recording of the incident on the CVR was erased due to the duration of the flight exceeding 2 hours.

The Captain and three Co-pilots prepared a cargo flight from Paris - Charles-de-Gaulle bound for Mexico City. While the two Relief Pilots carried out the exterior walkaround and checked that the load was safely in place, the Captain (PM) and the Co-pilot (PF) carried out the flight preparation in the cockpit.

The Co-pilot added up the various scheduled weights in his head and found a preliminary Take-Off Weight (TOW) of 243 tonnes instead of 343 tonnes. He entered this erroneous value in his On-board Performance Tool (OPT)[(3)]. The Captain added the supplementary fuel decided on by the crew to the TOW on the Operational Flight Plan (OFP) and obtained a correct weight of 343 tonnes. The Captain entered the same erroneous TOW (243 tonnes) into his OPT as that calculated by the Co-pilot. The Captain and the Co-pilot then cross-checked the take-off parameters calculated by their respective OPTs and obtained the same results.

The crew began to enter the OPT results, obtained from an erroneous TOW of 100 tonnes, in the FMS. The Co-pilot (PF) entered, in particular, the balance, an assumed temperature of 37°, a flap configuration of 5°, and the V1 of 143 kt calculated by the OPT[(4)]. The Captain was surprised that the calculated take-off speeds were about 20 kt below the reference speeds calculated by the FMS.

The crew decided to suspend entering the data until the end of the refuelling. They then performed other tasks.

The Relief Pilots returned to the cockpit. The Co-pilot (PF) performed the take-off briefing and stated in particular ''*we are heavy*''.

The Captain received the Final Loadsheet and announced the final load figure to the Co-pilot (PF). The latter recalculated on paper, the take-off weight based on the Dry Operating Weight (DOW), the payload and final fuel weight. He made a carrying over error and obtained 241.5 tonnes instead of 341.5 tonnes. He compared the new calculated value (241.5 tonnes) with that previously entered in his OPT (243 tonnes) and called out ''*it is consistent*''.

The Captain compared the Take-Off Weight (TOW) of the Final Loadsheet with the gross weight (GR WT)[(5)] displayed on the FMS and found that they were consistent. The latter was correct because it was calculated from the Zero Fuel Weight (ZFW) - which was correctly entered into the FMS by the crew - and the fuel on board automatically calculated by the aircraft.

When the refuelling was completed, both crew members went back to entering the speeds. This time, the reference speeds were no longer displayed and the crew unsuccessfully tried to display them by repeatedly pressing REF SPDS ON/OFF. None of the crew members understood why the reference speeds had disappeared.

The Captain and Co-pilot (PF) re-entered all the data in the FMS starting with the ZFW. The reference speeds calculated by the FMS were still not displayed.

[(3)]The OPT is a function of the EFB on Boeing 777.

[(4)]In the conditions of the day and with a correct TOW of 343 tonnes, the OPT would have given as results, a flap configuration of 15°, an assumed temperature of 58° and a V1 speed of 167 kt.

[(5)]''*Gross Weight*'' (GR WT) means the total weight at departure, including the fuel before taxiing, it has a similar value to the TOW.

The crew finally entered into the FMS, the take-off speeds calculated by the OPTs (V1=143 kt, VR=152 kt and V2=156 kt) for take-off. The flap configuration was 5°. This configuration surprised one of the Relief Pilots, but he did not express his misgivings.

The aircraft lined up for runway 26R from taxiway T12 and took off at 10:25.

The rotation was initiated when the Calibrated Air Speed (CAS) reached 154 kt. Just after the rotation, the PF and the three other crew members felt that the aircraft was sinking. Five seconds after rotation was initiated, the tailstrike protection was fully activated(6) . The main landing gear wheels were still in contact with the ground and the pitch stabilized at 9°, below the tailstrike pitch angle. From the beginning of the rotation, the Captain looked outside.

(6)The activations of the tailstrike protection were determined by Boeing from the QAR data of the event (cf. paragraph 1.16.1.2).

Eight seconds after the activation of the tailstrike protection, full thrust was applied in response to one of the Relief Pilots calling out "*TOGA!*" The aeroplane was then at a radio altitude of 16 ft, the pitch was 13°, the CAS 189 kt. The aeroplane clearly accelerated. The Captain was concerned about the height and the vertical speed. He ordered the retraction of the landing gear when the vertical speed was approximately +1500 ft/min. The pitch increased towards 16° and the aircraft flew over the opposite threshold 08L at a radio altitude of 172 ft.

The other Relief Pilot monitored the speed and helped the PF maintain the speed over the MMS(7) and the pitch under that of the PLI(8).

(7)Minimum Maneuvering Speed.

(8)Pitch Limit Indicator.

There was no approaching stall warning (Stick Shaker) during the take-off and climb.

Subsequently, the crew discussed several hypotheses as to the causes of the event. The error of 100 tonnes in the weight used was discovered when the PF consulted his OPT again. The PF was relieved at around FL200.

The crew members discussed whether to turn back but decided not to because they felt fit to continue the flight.

On arrival, the landing was normal. The crew members carried out an exterior walkaround and confirmed the absence of a tailstrike. After the flight, the crew members informed the operator about the event and were relieved of their duties.

1.2 Injuries to persons

	Injuries		
	Fatal	**Serious**	**Minor/None**
Crewmembers	-	-	**4**
Passengers	-	-	-
Others	-	-	-

1.3 Damage to aircraft

There was no damage to the aircraft.

1.4 Other damage

Not applicable.

1.5 Personnel information

1.5.1 Flight crew

1.5.1.1 Captain

❒ Male, 63 years old

- Airline Transport Pilot Licence ATPL(A).
- Boeing 777/787 Type Rating valid until 30 November 2015.
- Class 1 medical certificate valid until 7 November 2015.

Experience

- total: 21,331 flight hours, of which 13,511 hours as Captain;
- on type: 5,272 flight hours, all of which as Captain;
- in the last three months: 146 flight hours;
- in the last seven days: 0 hour.

1.5.1.2 Co-pilot

❒ Male, 45 years old

- Airline Transport Pilot Licence ATPL(A).
- Boeing 777/787 Type Rating valid until 31 March 2016.
- Class 1 medical certificate valid until 31 May 2016.

Experience

- total: 9,717 flight hours, of which 235 hours as Captain;
- on type: 1,328 flight hours, none of which as Captain;
- in the last three months: 153 flight hours;
- in the last seven days: 0 hour.

1.5.1.3 First Relief Pilot

❒ Male, 51 years old

- Airline Transport Pilot Licence ATPL(A).
- Boeing 777/787 Type Rating valid until 29 February 2016.
- Class 1 medical certificate valid until 31 January 2016.

Experience

- total: 11,662 flight hours, of which 2,861 hours as Captain;
- on type: 2,156 flight hours, none of which as Captain.

1.5.1.4 Second Relief Pilot

- ❒ Male, 39 years old
  - ■ Airline Transport Pilot Licence ATPL(A).
  - ■ Boeing 777/787 Type Rating valid until 30 November 2015.
  - ■ Class 1 medical certificate valid until 31 January 2016.

Experience

- ■ total: 6,208 flight hours, of which 120 hours as Captain;
- ■ on type: 3,940 flight hours, of which 12 hours as Captain.

1.6 Aircraft information

1.6.1 Airframe

Manufacturer	BOEING
Type	B777F28
Serial Number	32966
Registration	F-GUOC
Entry into service	07/02/2009
Airworthiness certificate	N° 119343 dated 25/02/2009 issued by the DGAC
Airworthiness review certificate	N° 2014/119343 119343 valid until 07/12/2015
Operation since major inspection	3,463 flight hours and 676 cycles
Operation as on 22 May 2015	28,850 flight hours and 4,729 cycles

1.6.2 Data entry procedure for Boeing 777 (Air France)

In the Air France FCOM in force on the day of the event, data entries are defined in the follow-ing procedures:

- ❒ FCOM-NP-AP-EFB-Procedure - Captain and First Officer
- ❒ FCOM-NP-AP-CDU-Preflight Procedure - Captain and First Officer
- ❒ FCOM-NP-AP-Before Start Procedure

The relevant elements for the analysis of the event are reproduced and described below:

❒ 1) FCOM-NP-AP-EFB Procedure - Captain and First Officer
Excerpts from the procedure are given below:

AIRFRANCE
777 Flight Crew Operations Manual

Normal Procedures -
Amplified Procedures

EFB Procedure - Captain and First Officer

To ensure EFB compliance with departure and arrival airport, the FMS route entries should be done prior to start the EFB procedure. Once the route is activated and executed, the EFB procedure may be started anytime during the preliminary preflight procedure.

[…]

Performance General

Each pilot enters separately coherent data in the EFB. At the most opportune moment, the entered data are compared and confirmed when both sides agree.

Once calculation is over for takeoff, reference speeds and data are compared and verified (at least Runway, TORA, Flaps, ATM, V2 and ZAC).

Once calculation is over for landing, Limit Weight or Landing Distance and Vref are compared.

[…]

Takeoff Performance Procedure

SHOW TAKEOFF .... Push if needed

PERFORMANCE - TAKEOFF Page:

[…]

Enter Takeoff Weight.

Note: Use W/B data from preliminary loadsheet. If the final weight is greater than the initial value or is lower of more than 5t, a new calculation is mandatory.

CALC .... Push

The procedure is carried out by the Captain and the Co-pilot. It can be started at any time during the Preliminary Preflight Procedure. However, the routes must be entered in the FMS beforehand, during the CDU Preflight Procedure.

The procedure specifies that each pilot enters the data independently, the entered data is compared and then the results of the calculations are compared.

Use of the W/B data from the Preliminary Loadsheet (the operational flight plan in this case) is stipulated. It is also written that it is mandatory to recalculate the performance parameters if the final weight of the Final Loadsheet is higher than the initial weight or is lower by more than five tonnes.

❒ 2) FCOM NP-AP-CDU Preflight Procedure - Captain and First Officer
Excerpts from the procedure are given below:

Normal Procedures -
Amplified Procedures

AIRFRANCE
777 Flight Crew Operations Manual

CDU Preflight Procedure - Captain and First Officer

Start the CDU Preflight Procedure anytime after the Preliminary Preflight Procedure. The Initial Data and Navigation Data entries must be complete before the flight instrument check during the Preflight Procedure. The Performance Data entries must be complete before the Before Start Checklist.

The Captain or First Officer may make CDU entries. The other pilot must verify the entries.

Enter data in all the boxed items on the following CDU pages.

Enter data in the dashed items or modify small font items that are listed in this procedure. Enter or modify other items at pilot's discretion.

Failure to enter enroute winds can result in flight plan time and fuel burn errors.

Initial Data .... Set

[…]

Navigation Data .... Set

RTE page:

Enter the route.

Method 1: route and winds uplink

[…]

Performance Data .... Set/Update

PERF INIT page:

Enter the ZFW.

Verify that the FUEL on the CDU, the dispatch papers, and EICAS agree.

Verify that the fuel is sufficient for flight.

Verify that the GR WT on the CDU and the dispatch papers agree.

THRUST LIM page:

Select an assumed temperature as needed.

The CDU Preflight Procedure begins after the Preliminary Preflight Procedure.

It is carried out by the Captain and the Co-pilot, one enters the data, and the other checks it[9].

The crew enters the ZFW in the FMS, checks the fuel quantity (FOB) and then compares the GR WT of the FMS with that of the Dispatch papers. Without this being explicit, this is the first entry of the initial ZFW taken from the OFP.

- 3) FCOM-NP-AP-Before Start Procedure
  Excerpt from the procedure is given below:

AIRFRANCE
777 Flight Crew Operations Manual

Normal Procedures - Amplified Procedures

Before Start Procedure

Start the Before Start Procedure after papers are on board.

Final loadsheet (ECD) .... Verified, Signed C, F/O

The Captain signs the final loadsheet.

Do the CDU Preflight Procedure – Performance Data steps: ZFW, CG.

Update, if necessary, EFB/PERFORMANCE/TAKEOFF parameters with final TOW and CG.

The Captain reads the takeoff parameters from the OPT:

•Flaps
•RWY/INTX
•TORA
•Reduced thrust temp
•N1
•TO Weight
•V1, VR and V2

The First Officer enters the takeoff parameters in the FMS: Flaps, Thrust and V Speeds.

The Captain checks the FMS takeoff parameters.

The Before Start Procedure only starts once the Final Loadsheet is on board.

The Final Loadsheet is checked by the two crew members. At Air France, the Final Loadsheet is sometimes kept by the Captain. In this case, he announces the load to the Co-pilot who recalculates the ZFW and then enters it in the FMS. This practice is still taught and is described in the Training Manual as follows:

> The Captain reads out the load.
> The F/O[10] calculates the ZFW value on the OFP, confirms it and then enters it on the PERF INIT page with these steps being cross-checked by the Captain.
> The Captain then reads out the MACTOW value, the F/O enters it on the PERF INIT page and enters the value rounded down to the next lowest whole number on the TAKEOFF REF page.
> After validation of the take-off parameters, the F/O enters the speeds V1, VR and V2 dictated by the Captain on the TAKEOFF REF page. The Captain also dictates the weight, the flap setting, the assumed temperature and the N1 for confirmation purposes (see FCOM NP> - Amplified procedures> - Before Start Procedure).

In the Before Start Procedure, the crew is requested to carry out the Performance Data steps (ZFW and CG)[11] of the CDU Preflight Procedure. This seems to suggest that the ZFW is entered in two steps, initially that based on the OFP and secondly that based on the Final Loadsheet but without it being clearly written.

[9] In the preamble, in the **FCOM NP Control Display Unit (CDU) Procedures**, it is stated: *Before taxi, the Captain or First Officer may make CDU entries. The other pilot must verify the entries. Make CDU entries before taxi or when stopped, when possible. If CDU entries must be made during taxi, the PM makes the entries. The PF must verify the entries before they are executed.*

[10] First Officer (Co-pilot).

[11] Centre of Gravity.

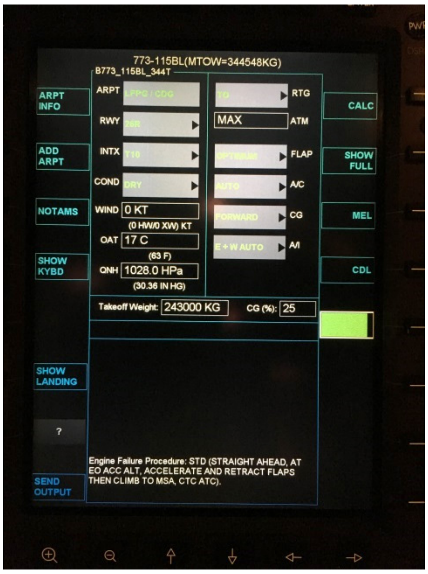
Then, the Captain reads the data on his OPT and the Co-pilot enters the flap configuration, thrust and take-off speeds in the FMS. The Captain checks the take-off parameters of the FMS.

1.6.3 On-board Performance Tool (OPT) and associated procedures

Air France has chosen to equip its Boeing 777 with the optional OPT offered by Boeing.

General view of Boeing 777 cockpit with the two OPTs

The manufacturer provides the parameter setting manual and the operator must configure the interface.



Example of parameter settings of Air France OPT

■ **Boeing 777 EFB/OPT procedure**

Boeing does not provide a procedure. At Air France, the OPT administrator is in charge of this procedure. It had been created in the airline's former operations manual, Part B (TU)[12]. When switching to the manufacturer's FCOM (cf. paragraph 1.17.2.3), it was reused without modification.

[12]Operating techniques.

At the time of the TU, no safety studies were carried out and the regulations in force at that time did not require it. There were also no safety studies during the transition to the manufacturer's FCOM.

■ **Preliminary Preflight Procedure and Before Start Procedure**

These procedures had been adapted by Air France to take into account the use of the Final Loadsheet and the OPT.

1.6.4 Reference speeds calculated by the FMS

On the Boeing 777, the FMS does not have access to the data calculated by the OPT, in particular the optimized take-off speeds. The FMS itself calculates take-off reference speeds (V1, VR, V2) based on parameters such as aircraft weight, temperature, take-off thrust configuration and flap configuration. These input parameters are either measured by the systems (example: fuel on board) or are entered by the crew in the FMS (example: ZFW).

As described in the Air France FCOM, once all the necessary data has been entered, the reference speeds are displayed on the TAKE OFF REF page.

Example of reference speeds displayed on FMS CDU

The reference speeds are displayed in the right-hand column with the captions REF V1, REF VR, REF V2. When the crew enters the take-off speeds, they replace the reference speeds and the captions REF V1, REF VR and REF V2 become respectively V1, VR and V2.

A REF SPDS (ON/OFF) button is used to display, in the ON position, the reference speeds in the central column, which makes it possible to display both the reference speeds and the entered speeds for comparison.

According to Boeing:

- some operators use these reference speeds for comparison with the speeds calculated by the Dispatch Office when carrying out the flight preparation;
- most operators do not use the reference speeds;
- some operators have aircraft that do not display the reference speeds.

Boeing does not give a tolerance threshold to be complied with when the crew compares the reference speeds and the entered speeds. Neither does Boeing describe the actions to be taken by the crew in the event of a difference being observed. Nor does Air France give any particular instructions to its crews.

In some cases, the FMS can calculate reference speeds while the OPT cannot calculate optimized speeds. This is the case, for example, if the available runway length is limited because the FMS does not take the runway length into account. Conversely, there are cases where the OPT can calculate optimized take-off speeds that can be used while the FMS cannot calculate reference speeds.

When certain data (ZFW, flap configuration, temperature, etc.) is modified by the user, the TAKE OFF SPEEDS DELETED message is displayed on the Control Display Unit (CDU) of the FMS. The reference speeds and take-off speeds that were displayed are deleted and the FMS recalculates the reference speeds.

The TAKE OFF SPEEDS DELETED message can be cleared by the crew and will not be displayed again unless the crew makes another entry that re-triggers the message.

1.6.5 V SPEEDS UNAVAILABLE message displayed on CDU of FMS

Overview

If the FMS cannot calculate the reference speeds, the V SPEEDS UNAVAILABLE message is displayed at the bottom of the CDU. It is displayed in white as are all the messages displayed on the CDU[13].

V SPEEDS UNAVAILABLE message

The V SPEEDS UNAVAILABLE message is one of the messages in the "*entry-error advisory messages*" category. It is associated with the "*Advisory*"[14]. amber "*FMC message*" displayed on the EICAS. No audio warning is generated.

[13] There are four FMC message categories: "*alerting messages*", "*communication messages*", "*advisory messages*" and "*entry-error advisory messages*".

[14] There are three alert levels for the messages displayed on EICAS: "*Memo*", "*Advisory*" and "*Caution*". Certain "*Caution*" type messages are associated with a "*Beeper*" (audio alert).

The V SPEEDS UNAVAILABLE message can be cleared by the crew and will not be displayed again unless the crew makes another entry that re-triggers the message.

Operator experience

Air France states:

- that in operation, few messages are displayed on the CDU during the flight preparation in the cockpit;
- that in the simulator, it is more common to see messages of this type. This is due to a bias in the use of the simulator (simulator reset for example);
- that before the incident, the V SPEEDS UNAVAILABLE message was not seen in training by the crews.

Conditions for display of message

According to Boeing, the six possible conditions for triggering the V SPEEDS UNAVAILABLE message are:

- 1. minimum control speeds on the ground (VMCG) or in the air (VMCA) cannot be satisfied (high thrust-to-weight combinations);
- 2. Lift Off Speed (VLOF) is predicted to exceed tire limit speed;
- 3. balanced V1 speed is predicted to exceed brake energy limit speed (VMBE);
- 4. minimum required climb gradient will be unavailable (minimum V2/VR ratio);
  5. calculated balanced field length exceeds the database limit of 16,000 feet;
- 6. take-off pressure altitude and/or OAT exceed the database limits.

Boeing informed the BEA that condition N° 4 had probably triggered the message at the time of the event.

FCOM documentation

The FCOM only mentions one of the six conditions for the display of the V SPEEDS UNAVAILABLE message:

- "*for certain high thrust/low gross weight takeoff conditions, FMS V–speeds are not calculated. Adjust gross weight and/or takeoff thrust limit to enable V–speed calculations*".

For this case only, the FCOM gives more details and in particular that take-off is not allowed:

- "*The FMS will protect for minimum control speeds by increasing V1, VR and V2 as required. However, the FMS will not compute takeoff speeds for weights where the required speed increase exceeds the maximum certified speed increase. This typically occurs at full rated thrust and light weights. In this case, the message "V SPEEDS UNAVAILABLE" will appear on the FMS scratchpad and the takeoff speed entries will be blank. Takeoff is not permitted in this condition as certified limits have been exceeded. The options are to select a smaller flap setting, select derate thrust and/or add weight (fuel). Selecting derate thrust is the preferred method as this will reduce the minimum control speeds. Note that the assumed temperature method may not help this condition as the minimum control speeds are determined at the actual temperature and therefore not reduced*".

What to do in the event of the appearance of the message

Boeing has stated that there are such situations and they may not be all that uncommon where the V SPEEDS UNAVAILABLE message appears while the optimized speeds calculated by the OPT can be used to take off (for example when the FMS calculations specify speeds which exceed the tire maximum speed). In these cases, the V SPEEDS UNAVAILABLE message appears, and the crew can enter in the FMS, the optimized speeds calculated by the OPT to take-off.

Following the incident, the BEA asked Boeing what the crew should do if the V SPEEDS UNAVAILABLE message appears to determine if take-off was possible. Boeing told the BEA that each operator could have different methods and procedures.

Loss of protection against the entry of minimum speeds calculated by the FMS

In a normal situation, when a V1, VR, or V2 speed below the minimum speed calculated by the FMS is entered, the title of the corresponding line is modified to MINV1, MINVR or MINV2, and the minimum value is displayed instead of the speed.

This protection is no longer available when the FMS cannot calculate the reference speeds (V SPEEDS UNAVAILABLE message). The crew is not notified of the loss of this protection. In this case, the crew can enter any V1, VR or V2 speed values greater than 80 kt.

Similar messages on other Boeing aeroplanes

On the Boeing 737, the generic FCOM specifies for the V SPEEDS UNAVAILABLE message that the "*FMS cannot compute V speeds (as installed) due to unreasonable inputs on the RTE, PERF INIT, or TAKEOFF REF pages FMS*" and "*Correct inputs that affect V speed computation*".

On the Boeing 787, there is a MIN V SPEEDS UNAVAILABLE message. When it is displayed, a help window displays UNABLE TO COMPUTE TAKEOFF SPEEDS FOR CURRENT CONDITIONS. It is the integrated EFB which is used to calculate take-off speeds. The FMS does not calculate reference speeds. The FCOM states that the triggering condition is as follows: "*The EFB cannot compute takeoff speeds for the current high thrust/low gross weight condition. Adjust gross weight and/or thrust limit to enable calculation of takeoff speeds*". In the 787 KLM FCOM, it is written that when this message appears, take-off is not allowed because the certification limits have been exceeded.

1.6.6 Optimization of flap configuration at take-off

The deployment of the OPT at Air France began in 2007. Boeing 777-F (cargo) were concerned from the beginning of 2009.

The move to optimizing the flap configuration (called OPTI flaps) took place in June 2014.

Before performance optimization, the preferred flap configuration was 5° on 777-200 and 15° on the 777-300 and 777-F (cargo).

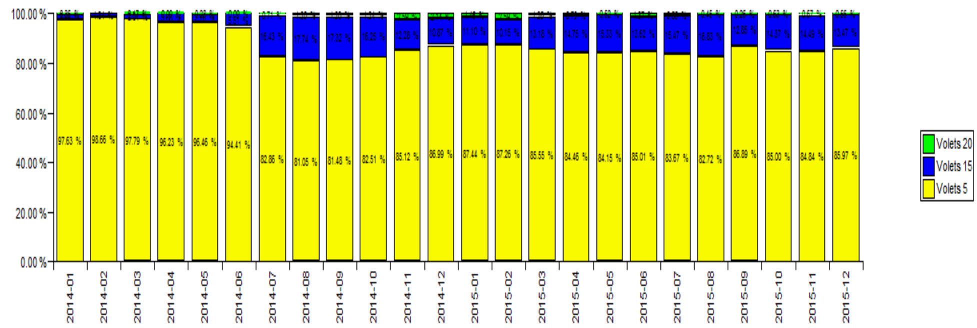
The lower flap setting has a beneficial effect on performances for low weight aircraft and/or for long runways: the transition to optimization is marked by a clear increase in the use of a flap setting at 5° instead of 15° for 777-F (cargo) aeroplanes.

Air France conducted a safety study that forecast the statistics of the network with optimization of the flap configuration at take-off. Below is an excerpt of the results of this Air France study:

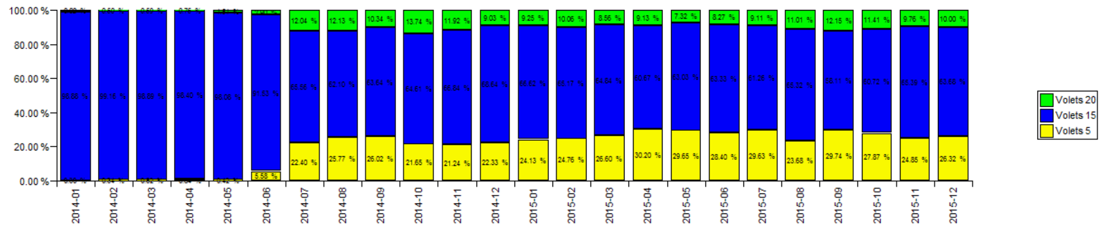
Aeroplane type	% flap setting at 5°	% flap setting at 15°	% flap setting at 20°
Boeing 777-200	94.9 %	4.9 %	0.3 %
Boeing 777-300	27.8 %	63.4 %	8.8 %
Boeing 777-F (cargo)	91.6 %	8.4 %	0.0 %

These figures are relatively consistent with the following monitoring:

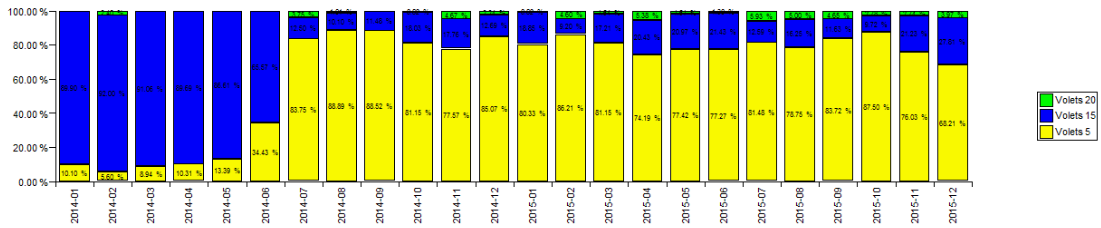
Boeing 777-200



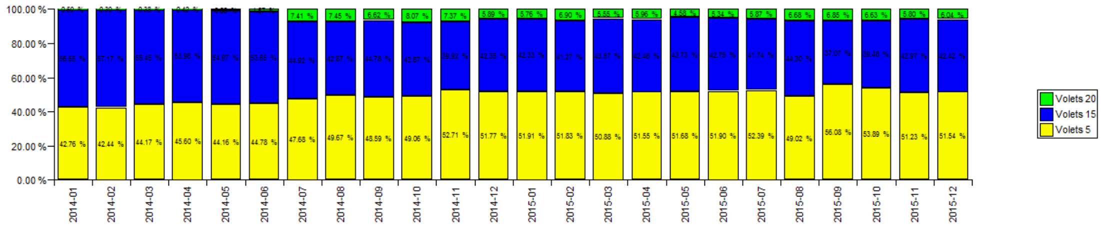
Boeing 777-300



Boeing 777-F



Global Boeing 777



The calculation of the performance parameters on the OPT was already in effect when the optimization philosophy of the flap configuration at take-off was introduced.

1.6.7 TAIL STRIKE procedure

The TAIL STRIKE procedure in the Air France QRH is as follows:

[] TAIL STRIKE

Condition: The tail hits the runway.

Caution! Do not pressurize the airplane. Pressurizing the airplane may cause further structural damage.

1 OUTFLOW VALVE switches (both) . . . . MAN

2 OUTFLOW VALVE MANUAL switches (both) . . . . .Hold in OPEN until the outflow valve indications show fully open to depressurize the airplane

3 Plan to land at the nearest suitable airport.

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

CABIN ALTITUDE AUTO

■ ■ ■ ■

The input criteria in this procedure is a suspected tailstrike or an effective tailstrike.

1.7 Meteorological information

The 10:30 METAR at LFPG gave the following conditions:

❒ LFPG 221030Z VRB04KT 9999 SCT034 17/07 Q1027 NOSIG=

1.8 Aids to navigation

Not applicable.

1.9 Communications

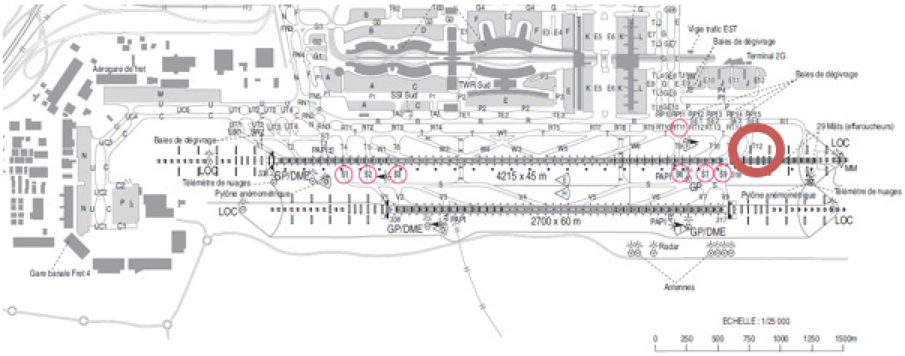
Not applicable.

1.10 Aerodrome Information

Paris - Charles-de-Gaulle airport is open to public air traffic. It has four runways.

F-GUOC took off on runway 26R from taxiway T12.

The TORA and ASDA distances from T12 are 3,735 m. The TODA is 3,795 m.

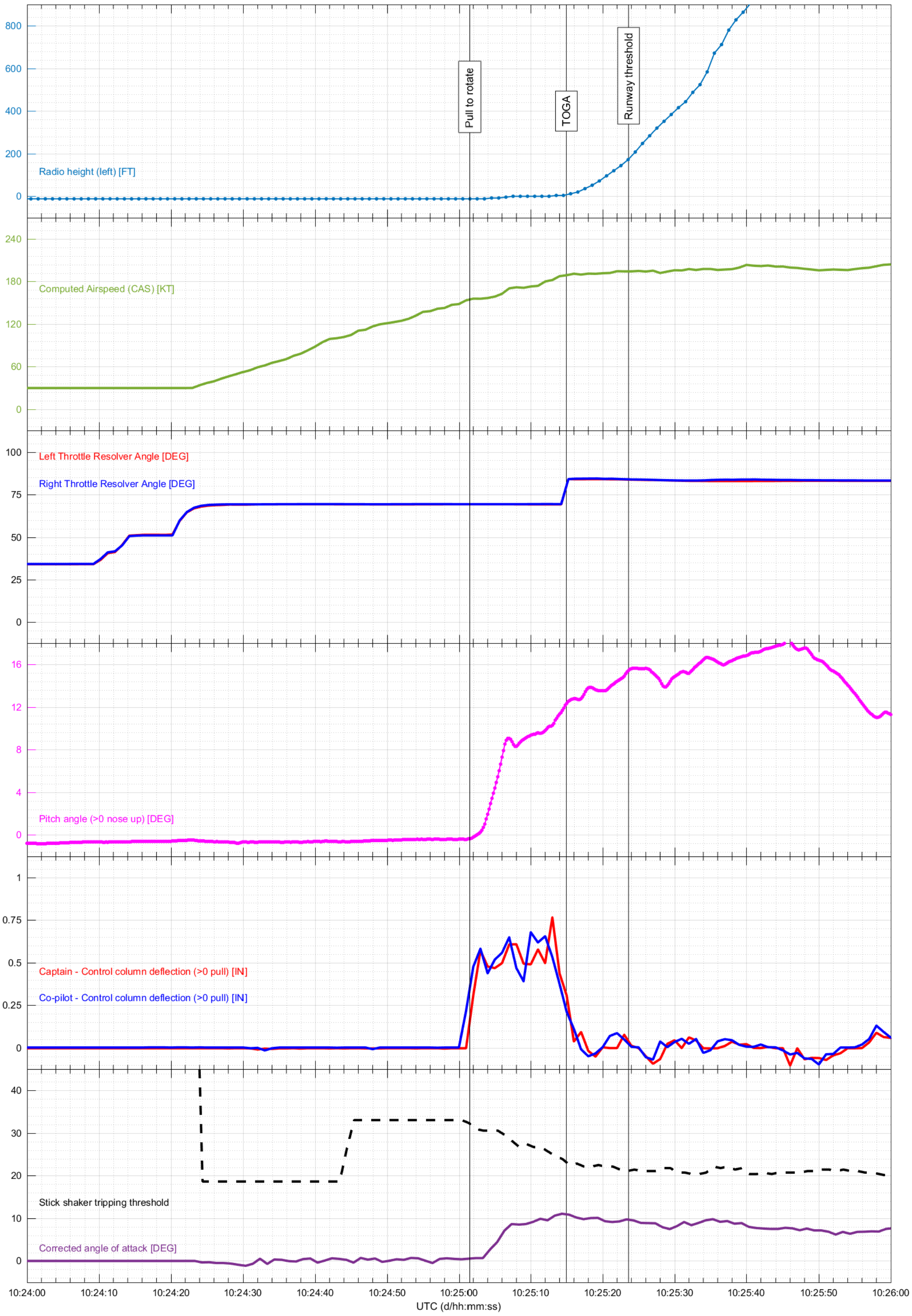


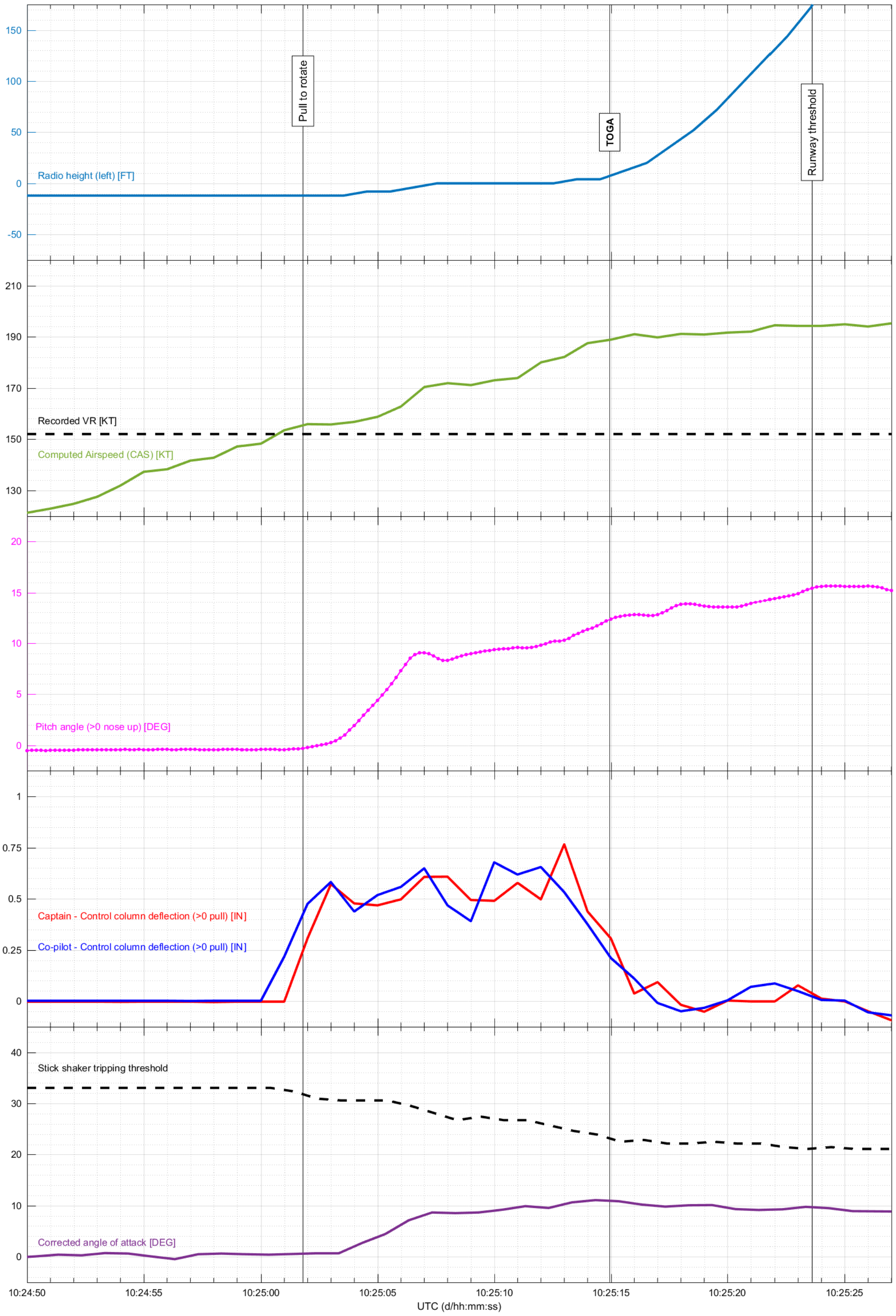
1.11 Flight recorders

In accordance with the regulations in force, the aeroplane was equipped with a FDR and a CVR. The aeroplane also had a QAR.

The two-hour recording capability of the CVR made it impossible to recover the audio data for the event.

The parameters were analysed from the QAR. The parameters extracted are shown below.


Pull to rotate
TOGA
Runway threshold
Radio height (left) [FT]
Computed Airspeed (CAS) [KT]
Left Throttle Resolver Angle [DEG]
Right Throttle Resolver Angle [DEG]
Pitch angle (>0 nose up) [DEG]
Captain - Control column deflection (>0 pull) [IN]
Co-pilot - Control column deflection (>0 pull) [IN]
Stick shaker tripping threshold
Corrected angle of attack [DEG]
UTC (d/hh:mm:ss)



Pull to rotate
TOGA
Runway threshold
Radio height (left) [FT]
Recorded VR [KT]
Computed Airspeed (CAS) [KT]
Pitch angle (>0 nose up) [DEG]
Captain - Control column deflection (>0 pull) [IN]
Co-pilot - Control column deflection (>0 pull) [IN]
Stick shaker tripping threshold
Corrected angle of attack [DEG]
10:24:50
10:24:55
10:25:00
10:25:05
10:25:10
10:25:15
10:25:20
10:25:25
UTC (d/hh:mm:ss)

1.12 Wreckage and impact information

Not applicable.

1.13 Medical and pathological information

Not applicable.

1.14 Fire

Not applicable.

1.15 Survival aspects

Not applicable.

1.16 Tests and research

1.16.1 Simulations performed by Boeing

1.16.1.1 Take-off speeds and reference speeds

Boeing confirmed that the take-off speeds used by the crew corresponded to the speeds calculated with the conditions of the day for the erroneous weight entered by the crew in the EFB.

In addition, Boeing determined that from a weight calculated by the FMS (ZFW + fuel on board) of 330 tonnes, a 5° flap configuration and under the conditions of the day:

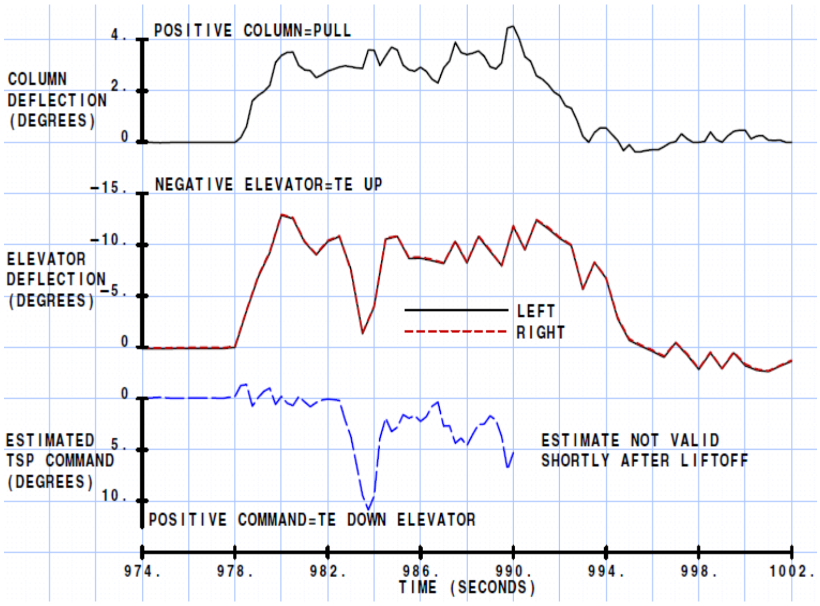
- the FMS was no longer able to calculate reference speeds;
- the V SPEEDS UNAVAILABLE message was generated.

1.16.1.2 Tailstrike Protection

The TailStrike Protection (TSP) acts automatically on the elevators to avoid a tailstrike in the take-off or landing phases. The TSP input and the crew input are added together to form the overall control input. The TSP input is limited to 10°, which allows the crew to counter the protection, if necessary, by a nose-up input. The TSP input is determined by an excessive closing rate between the tail and the ground and the height of the tail with respect to the runway, calculated from the radio altitude, the pitch, the pitch rate and the vertical speed of the aeroplane.

The flight recorder data does not contain the TSP activation data.

However, Boeing was able to estimate the activation of this protection by comparing the crew inputs on the elevator control and the position of the elevators. This calculation is possible only during the ground phase and during the rotation. It is then possible to directly link the elevator control and the control surface position. The difference between the expected position and the actual recorded position is attributed to the activation of the TSP. This difference in degrees is the activation level of the protection (from 0 to 10).



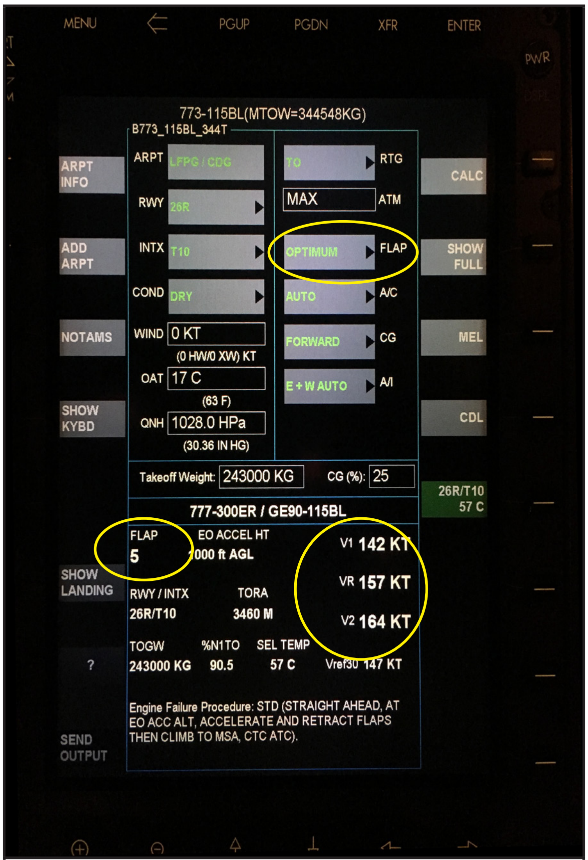
Estimated TSP (TailStrike Protection) input - Boeing calculations

Boeing concluded that the TSP was fully activated a first time around five seconds after the start of the rotation and a second time, to a lesser extent, just after take-off.

Boeing estimated that without the TSP and on the assumption that the column input had remained unchanged, the aeroplane tail would have struck the ground around 1.1 seconds after the point of activation of the tailstrike protection.

1.16.2 Simulator session conducted by the BEA

The BEA reenacted, in an Air France simulator, the entry of the data in the OPT and the FMS as it had been done by the crew during the flight preparation of the incident. The simulator used corresponded to a Boeing 777-300. Consequently, the values of the performance calculations do not correspond exactly to those of the event. Nevertheless, the data collected is representative of the incident.



1.

The TOW entered in the OPT is erroneous: 243 tonnes instead of 343 tonnes.

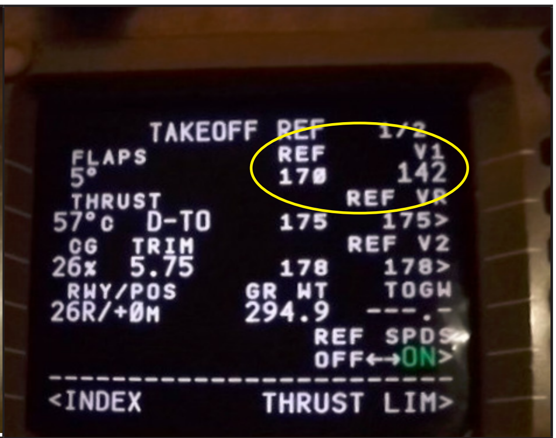
The results obtained are:

- ❒ Flap configuration = 5°
- ❒ Take-off speeds V1 = 142 kt, VR = 157 kt, V2 = 164 kt

2.

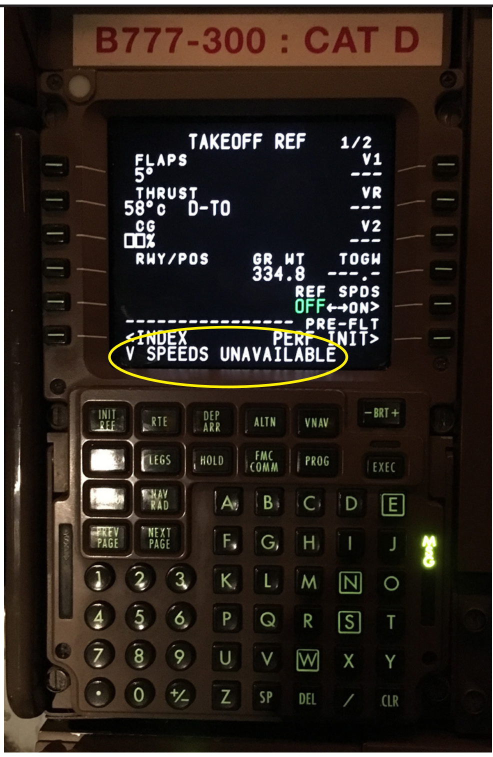
Refuelling is in progress.

The GR WT is calculated by the FMS from the ZFW and the measured FOB.



3.

The reference speeds are displayed. V1 is entered by the crew. **V1 REF is much higher** than the V1 calculated for a weight 100 tonnes lower.

<table>
<tr>
<td>
</td>
<td>
</td>
</tr>
<tr>
<td>4.
Refuelling is still in progress.
When the calculated GR WT reaches 334.8 tonnes, the TAKE OFF SPEEDS DELETED message is displayed. This message can be deleted and in this case the V SPEEDS UNAVAILABLE message is displayed. This message can be deleted.
The reference speeds are no longer displayed.</td>
<td>5.
Refuelling is completed.
The crew enters the OPT results in the FMS. (If the crew completely re-enters the take-off parameters, the V SPEEDS UNAVAILABLE message is displayed again).
The FMS allows take-off speeds to be entered.</td>
</tr>
</table>

1.17 Organizational and management information

1.17.1 Risk management by Air France

Following an incident further to the use of a 100-tonne erroneous parameter in July 2004 on an A340 aircraft in its fleet, Air France carried out around fifteen corrective actions. These included:

- an analysis of the use of erroneous parameters, notably on the basis of incident reports made by the crews (ASR in particular);
- a request to Airbus and Boeing for the systems to have a protection that prevents the entry of a V1 speed greater than VR and/or V2;
- a simulator session dedicated to readjusting the thrust and to the application of a new briefing;
- an improvement to the Take-off Card[15].

[15]The occurrence take-off card is given in paragraph 1.18.2.

In 2007, Air France set up a working group to develop principles for using on-board performance calculation tools, in order to reinforce the protection against calculation errors and use of erroneous parameters at take-off. The work of this group ended in 2010 without all the analyses being completed. Aircraft manufacturers had in fact provided a set of procedures and EFBs while Air France was studying a self-developed laptop solution for on-board performance computation. As a consequence, Air France considered that the working group was no longer relevant.

At the same time, Air France participated in the safety study published by the BEA in 2008 concerning the use of erroneous parameters at take-off (cf. paragraph 1.18.5).

In 2009, flight safety information on this topic was published in the Boeing 777 sector.

The use of erroneous parameters was also reviewed during ground training and during crew flight proficiency checks.

Internal audit flights conducted as part of the compliance monitoring programme provided another opportunity for Air France to observe its procedures in operational situations. The auditor pilots were generally not qualified on the same type of aeroplane. This principle was intended to ensure the independence of the audit.

The use of erroneous parameters at take-off was an item that was observed during the LOSA campaigns in 2012 and 2015(16).

In addition, the first steps undertaken by Air France to detect entry errors through Flight Data Monitoring (FDM) started in August 2014. Two criteria were studied based on the following data:

- the angle of attack on take-off;
- the V2/VS1g ratio(17), which must be greater than 1.13.

Air France stated that it did not receive sufficient assistance from the manufacturers to correctly analyse the angle of attack parameter.

The second solution is currently being analysed. It is not always possible to detect the use of erroneous parameters when V2 is low. About thirty cases on Airbus A320 have been detected, one on Boeing 777 (F-GUOC serious incident) and one on Airbus A330/A340. On A320, most of the cases detected by this test have been shown to be TOW entries instead of ZFW entries in the FMS.

Air France abides by the conclusions of the EOFDM(18) working group that recommended monitoring the FDM precursors related to take-off performance. Nevertheless, Air France indicates that EASA's work is quite theoretical and that the difficulty is to find accurate information in the recordings.

1.17.2 Oversight of air operations

1.17.2.1 European regulatory texts relating to air operations

Commission Regulation (EU) N° 965/2012 (known as Air OPS) is applicable since 28 October 2012(19). The Air OPS requirements common to all types of operations and applicable to the authorities are described in Part-ARO, which is Annex II of the Regulation. Those applicable to the operators appear in Part-ORO, which constitutes Annex III of the regulation.

(16) The BEA was unable to obtain the results or lessons learned from the observations made in this context due to the confidentiality of the audit.

(17) Stall speed at 1g load factor.

(18) European Operators Flight Data Monitoring.

(19) Commission Regulation (EU) N° 965/2012 of 5 October 2012 laying down technical requirements and administrative procedures related to air operations pursuant to Regulation (EC) N° 216/2008 of the European Parliament and of the Council.

The Air OPS specifies the different items that require prior approval by the competent authority. This is the case, in particular, for the use of an EFB incorporating a weight and balance calculation to generate the take-off parameters[20].

To enable an operator to implement changes for other items without prior competent authority approval in accordance with ORO.GEN.130, the competent authority shall approve the procedure submitted by the organisation defining the scope of such changes and describing how such changes will be managed and notified (see point (c) of ARO.GEN.310). This possibility applies to the modifications of the operator's management system (excepting items relating to ORO.GEN.200 (a)(1) and (2)) and of the operational procedures, such as those relating to the calculation and entry of take-off parameters.

As part of the ongoing oversight, all processes should be completely audited by the authority at periods not exceeding the applicable oversight planning cycle of two to four years.

Ultimately, it is expected that the regulation will be amended to extend the scope of the EFB functions subject to a prior approval. This will also include performance calculation applications. Without waiting for this amendment, the DSAC maintains the approval requirement that it applied before the Air OPS. To do so, it is supported notably by AMC 20-25 (cf. paragraph 1.17.3.3).

Prior to the taking effect of the Air OPS, air operations were governed by Commission Regulation (EC) N° 859/2008 (known as EU-OPS)[21]. EU-OPS did not specify the examination methods to be applied by the competent authority, prior to issuing an AOC or to the acceptance of a change. With respect to the approval of procedural changes, only the items approved in the operator's AOC required approval by the authority. For other items, the spirit of the EU-OPS was that the airline informed the competent authority and that the latter checked the conformity of the procedures.

1.17.2.2 Safety recommendations addressed to the DGAC and related replies

The DGAC was the addressee of two safety recommendations relating to the use of erroneous parameters at take-off. They were issued as part of the study published by the BEA in 2008[22], with which the DGAC was associated.

Recommendations	Summary of the replies from the DGAC
BEA (FRAN-2008-014), addressed to the DGAC Safety Study, 2008[23] *"The DGAC shall in liaison with FAA and EASA improve the certification so that computers trigger* ***crew warnings or activate protection systems when inconsistent data are inputted****, obviously erroneous or far from usual values".*	❒ In August 2008, the DGAC stated that it supported this recommendation and had forwarded the BEA study and the associated recommendation to EASA.

[20] Cf. Annex IV (Part-CAT) Section 3 – Chapter 1 - CAT. POL.MAB.105(e).

[21] Commission Regulation (EC) N° 859/2008 of 20 August 2008 amending Council Regulation (EEC) N° 3922/91 as regards common technical requirements and administrative procedures applicable to commercial transportation by aeroplane.

[22] Cf. paragraph 1.18.5.

[23] https://www.bea.aero/etudes/use.of.erroneous.parameters.at.takeoff/use.of.erroneous.parameters.at.takeoff.pdf

BEA (FRAN 2008-022)	
BEA (FRAN 2008-022) Safety Study, 2008 *"The DGAC ensures that French operators:* *1. make their pilots and the relevant ground personnel aware of the specific error processes at the departure of the flight, the degradation of performances and the risks associated with the use of erroneous parameters at take-off,* *2. have actually implemented robust procedures by which the flight crew generates and validates the parameters used at take-off".*	In September 2008, the DGAC replied to both items of the recommendation. **Item 1** ❒ The DGAC referred to the study in a safety bulletin. ❒ The DCS[24] gives instructions to entities responsible for overseeing operators with regard to the assimilation of the recommendation, particularly in terms of CRM and awareness of ground personnel. **Item 2** ❒ The DCS gives instructions to the entities responsible for overseeing operators to verify that the procedures in place limit the entry of erroneous parameters. In particular, it asks them to verify that the parameters are prepared independently, that the verification of the order of magnitude is the subject of a cross-check by the other pilot, that time is left to the crews to make this check, to modify the manuals if the previous provisions are not in place, and to encourage voluntary feedback from crews about incidents.

[24]The DCS was, within the DGAC, the entity responsible for overseeing operators. It was based at the regional level on the DACs. The DSAC was established on 1 January 2009 as a national oversight service, replacing the DCS and DACs.

1.17.2.3 Oversight by the DSAC

The DSAC is the authority responsible for the oversight of air operators in France. The oversight of Air France is exercised by the DSAC headquarters.

Since the DGAC's replies to the recommendations issued by the BEA in 2008, several developments have affected the oversight of Air France's operations by the DSAC, particularly with regard to the risk associated with the use of erroneous parameters at take-off. In particular:

- ❒ At the end of 2008, the French decree concerning Safety Management Systems (SMS) was published[25]. Since then, part of the oversight activity carried out by the DSAC consists in ensuring that the operators have processes enabling them to manage the risks to which they are exposed.
- ❒ The commissioning of the EFBs continued at Air France, and began in 2009 for the Boeing 777-F fleet.
- ❒ After the accident of the Airbus A330 registered F-GZCP on 1 June 2009, Air France decided to switch part B of the operating manual for its entire fleet to new documentation called FCOM, directly based on the manufacturer's documentation of the same name. The previous Air France documentation consisted of procedures derived from the manufacturer's data, which the company had chosen to customize in order to appropriate them. By opting for the manufacturer's documentation for most of its procedures, the company aimed to guarantee compliance with the manufacturer's standards and benefit from its feedback. The change was made between 2009 and 2012.
- ❒ In 2012, the Air OPS was published (cf. paragraph 1.17.2.1).

[25]French decree of 22 December 2008 with respect to the implementation of safety management systems for commercial air transport operators and maintenance organizations

The DSAC monitored the process implemented by Air France between 2009 and 2012, leading to the change of its operating manual. The DSAC did not formally approve the content of the FCOM. Under the EU-OPS and then Air OPS regulations, this approval was not required.

As part of the SMS monitoring, the DSAC set up an «*evaluation of use of good practices*». This included checking how the operators take into account the relevant publications (SIB, safety info, etc.). Within this scope, the procedures relating to the calculation and entry of take-off parameters of all Air France fleets were considered satisfactory.

The DSAC details its oversight policy and procedures in the Technical Inspection Manual (MCT) which complies with Air OPS. The MCT lists, in a table, the changes for which AOC holders must obtain prior approval from the DSAC. This list mentions the use of the EFB (in connection with AMC 20-25). On the other hand, procedures for calculating and entering take-off parameters are not included in this list. However, the MCT points out that this is an area to be verified as part of the flight checks.

At the beginning of 2014, the following item was added to the verification list of the DSAC flight checks: Has a means of detecting the use of an erroneous parameter been implemented (Choice of take-off speeds / entry of Final Loadsheet data in FMS or equivalent). In 2014 and 2015, the DSAC carried out 83 flight checks at Air France, including 15 on Boeing 777. This item was considered perfectible only once: it concerned a check on a 777 and the FOI[(26)] had found that the pilots' knowledge of the orders of magnitude could have been improved.

[(26)] Flight Operations Inspector.

The DSAC considered that until the F-GUOC serious incident occurred, a large number of checks had been made, without producing a signal that would have prompted it to request a change in the procedures.

1.17.3 Consideration of the issue of use of erroneous parameters by civil aviation authorities

1.17.3.1 Handling of safety recommendations by EASA

The European Aviation Safety Agency (EASA) started operating in 2003. Among other tasks, the agency is responsible for drafting Community regulations on aviation safety. It is also responsible for the certification and oversight of aircraft airworthiness. In these respects, between 2004 and 2012, EASA was the direct or indirect addressee of eight safety recommendations related to the issue of use of erroneous parameters.

These recommendations were mainly made in the context of safety investigations following accidents or serious incidents. They were also issued or recalled during the safety study published by the BEA in 2008.

<table>
<tr><th>Recommendations</th><th>Summary of EASA replies</th></tr>
<tr><td>BEA (FRAN-2005-001)
Accident B727, 25/12/2003, Cotonou[27]

“the Civil Aviation Authorities, in particular the FAA in the United States and EASA in Europe, modify the certification requirements so as to ensure the presence, on new generation airplanes to be used for commercial flights, of on-board systems to determine weight and balance, as well as recording of the parameters supplied by these systems.”</td><td>❒ At the end of 2006, EASA notified it agreed with the recommendation and planned to include it among EUROCAE’s tasks.

❒ At the end of 2010, the DSAC requested a progress report. EASA stated that a preliminary study would be carried out, that the recommendation would be sent to the EUROCAE group and that a task had been included in its regulatory work program.

❒ In June 2013, EASA announced that the WG-88 concluded that it was possible and recommended to standardize On-Board Weight and Balance Systems (OBWBS). It was stated that the WG-88 would now be working on drafting MOPS and that EASA would later decide whether a rule would be appropriate.</td></tr>
<tr><td>TSB (CAND-2006-007)
Accident B747, 14/10/2004, Halifax[28]

The Board recommends that the Department of Transport, in conjunction with the International Civil Aviation Organization, the Federal Aviation Administration, the European Aviation Safety Agency, and other regulatory organizations, establish a requirement for transport category aircraft to be equipped with a take-off performance monitoring system that would provide flight crews with an accurate and timely indication of inadequate take-off performance.</td><td>❒ In June 2014, EASA explained that there was no standard and that the technical feasibility of Take-Off Performance Monitoring Systems (TOPMS) had not been proven.

❒ EASA recalled, however, that a EUROCAE working group (WG-94) was dedicated to TOPMS. It stated that this working group was preparing a technical report on the state of the art and the desirability of technical standardization.</td></tr>
<tr><td>DSB (NETH-2007-004)
Accident MD-88, 17/06/2003, Groningen[29]

It is recommended to the Civil Aviation Authority, the Netherlands (IVW) to develop certification requirements for aircraft from the civil aviation category, to provide weight and centre of gravity measurements to the crew of new aircraft and to investigate the possibility to provide these data with existing aircraft.</td><td>❒ In June 2013, EASA announced that the WG-88 had concluded that it was possible and recommended to standardize OBWBS. It was stated that the WG-88 would now be working on drafting MOPS and that EASA would later decide whether a regulation would be appropriate.</td></tr>
</table>

(27) https://www.bea.aero/fileadmin/documents/docspa/2003/3x-o031225a/pdf/3x-o031225a.pdf

(28) http://www.tsb.gc.ca/fra/rapports-reports/aviation/2004/a04h0004/a04h0004.pdf

(29) https://www.onderzoeksraad.nl/en/media/attachment/2018/7/10/2006004e_runway_overrun_onur_air.pdf

Recommendations	Summary of EASA replies
BEA (FRAN-2008-014), addressed to the DGAC Safety Study, 2008[30] *"The DGAC shall in liaison with FAA and EASA improve the certification specifications so that* ***computers trigger crew warnings or activate protection systems when inconsistent data are inputted****, obviously erroneous or far from usual values".*	❒ In **August 2008**, the DGAC stated that it supported this recommendation and had forwarded the BEA study and the associated recommendation to EASA. The DGAC stated that the FAA had produced a circular to certify on-board equipment for determining weight and balance. ❒ In **December 2011**, EASA explained that various systems under development could help detect discrepancies among the parameters entered for take-off. However, their potential was not known to EASA at the time and the agency stated that it would need to further investigate these features before they could be certified or made mandatory. ❒ EASA recalled the creation of EUROCAE working groups **WG-88 (OBWBS)** and **WG-94 (TOPMS)**. The agency then clarified that WG-88 had started working on the MOPS for OBWBS and that the task of WG-94 was to review the state of the art for TOPMS. EASA also mentioned certification and approval work on EFBs. ❒ In **February 2014**, EASA reported that WG-88 was preparing the MOPS for OBWBS, the feasibility study had been favourable, and that the agency had opened a RuleMaking Task on the subject (RMT.0116). EASA stated that WG-94 was still studying the feasibility of the TOPMS and that the EFB was subject to a NPA (Notice of Proposed Amendment) with AMC (Acceptable Means of Compliance). ❒ In **April 2015**, EASA recalled that functions of this type already existed but that they were not sufficient to mitigate all potential errors. In particular, EASA stated that gross errors may exist while remaining in the performance envelope. EASA said it is exploring other ways of improvement. EASA explained that the **AMC** relating to the **EFB** were in force. It recalled that the **WG-88** was still drafting the **MOPS** relating to the **OBWBS**. On the other hand, EASA explained that **WG-94** had been terminated after having concluded that the development of standards to define performance requirements and operational conditions for **TOPMS** is not possible at the moment. Despite this conclusion, EASA stated that the search for technical solutions must be pursued by the industry and that these developments would be monitored.

[30] https://www.bea.aero/etudes/use.of.erroneous.parameters.at.takeoff/use.of.erroneous.parameters.at.takeoff.pdf

Recommendations	Summary of EASA replies
AAIB (UNKG-2009-080) Serious grave A330, 28/10/2008, Montego[31] Bay *"It is recommended that the European Aviation Safety Agency develop a specification for an* ***aircraft take-off performance monitoring system*** *which provides a timely alert to flight crews when achieved take-off performance is inadequate for given aircraft configurations and airfield conditions".*	❒ In **September 2011**, EASA explained that there was no standard for **TOPMS**, and that their effectiveness had not been proven. EASA explained that a EUROCAE working group had been set up **(WG-94)** to study the state of the art and the feasibility of such systems. ❒ In **April 2015**, EASA stated that **WG-94** had been terminated after having concluded that the development of standards to define performance requirements and operational conditions for **TOPMS** is not possible at the moment. On the other hand, the agency explains that **AMC** relating to the **EFB** were in force and that the **WG-88** was still drafting the **MOPS** relating to **the OBWBS**.
AAIB (UNKG-2009-081) Serious incident grave A330, 28/10/2008, Montego Bay *"It is recommended that the European Aviation Safety Agency establish a requirement for transport category aircraft to be equipped with a* ***take-off performance monitoring system*** *which provides a timely alert to flight crews when achieved take-off performance is inadequate for given aircraft configurations and airfield conditions".*	❒ In **September 2011**, EASA explained that there was no standard for **TOPMS**, and that their effectiveness had not been proven. EASA explained that a EUROCAE working group had been set up **(WG-94)** to study the state of the art and the feasibility of such systems.
BEA (FRAN-2011-032) Serious incident Boeing 737, 16/08/2008, Paris[32] *"The BEA recommends that EASA conduct a study on the standards that should be taken into account during certification of* ***on-board performance calculation systems****, in order to ensure that their* ***ergonomics*** *and procedures for use are compatible with the requirements of safety".*	❒ In **December 2013**, EASA explained that a call for tenders had been made for a study into good practices and the evaluation of the use of **EFBs**.

[31] https://assets.publishing.service.gov.uk/media/5422f05640f0b613420002ad/Airbus_A330-243__G-OJMC_11-09.pdf

[32] https://www.bea.aero/docspa/2008/su-z080816.en/pdf/su-z080816.en.pdf

Recommendations	Summary of EASA replies
AAIB (UNKG-2012-036) Accident Boeing 737, 14/04/2012, Chambery[33] *"It is recommended that the European Aviation Safety Agency establish a set of detailed guidelines for the operational evaluation and approval of Electronic Flight Bags. These should be more specific than the proposed Acceptable Means of Compliance (AMC) 20-25 and include information such as provided in the Federal Aviation Authority document 'Electronic Flight Bag Authorization for Use' and Joint Aviation Authorities Safety Information Communication No7".*	❒ In **February 2014**, EASA stated that the draft AMC for **EFBs** had significantly evolved during the NPA 2012-02 consultation phase.

(33) https://assets.publishing.service.gov.uk/media/5423018de5274a1314000ab5/Boeing_737-33A_G-ZAPZ_04-13.pdf_

1.17.3.2 Handling of safety recommendations by other civil aviation authorities

On 12 March 2003, the tail of a Boeing 747 struck the runway and incurred substantial damage during the take-off rotation at Auckland International Airport in New Zealand. In 2006, following the investigation[34] conducted by the TAIC, the NTSB addressed five safety recommendations to the FAA:

(34) https://taic.org.nz/sites/default/files/inquiry/documents/03-003.pdf

- ❒ (A-05-003) to require "*Honeywell to modify its flight management system (FMS) software to annunciate warnings to the flight crew when a take-off reference speed is changed by a value that would impede the airplane's ability to safely take off, and require all operators of airplanes with Honeywell FMS computers to incorporate this software modification*".
- ❒ (A-05-004) to require "*Honeywell to modify its flight management system (FMS) software to prevent entry of airplane weights that would result in landing weights below zero fuel weight or operating empty weight, and require all operators of airplanes with Honeywell FMS computers to incorporate this software modification*".
- ❒ (A-05-005) to require "*Honeywell to modify its flight management system (FMS) software either to inhibit manual entries in the gross weight field or to allow the take-off gross weight to be uplinked directly into the FMS, and require operators of airplanes with Honeywell FMSs to incorporate this software modification*".
- ❒ (A-05-006) to require "*Honeywell to conduct a study of its flight management system computers to identify any additional improvements that may be necessary for error checking and confirming that the entered take-off and landing performance information is correct and reasonable*".
- ❒ (A-05-007) to require "*companies other than Honeywell that manufacture flight management systems (FMS) that are installed on 14 Code of Federal Regulations Part 25 airplanes to study their FMS computers to identify any improvements that may be necessary for error checking and confirming that the entered take-off and landing performance information is correct and reasonable*".

To address these safety issues by alternative means, the FAA requested a comprehensive review of these safety recommendations by the Air Transport Association CNS[35] task force. Through this review, the FAA encouraged FMS manufacturers to investigate methods of error checking which are functionally effective, meet accepted human factor guidelines, and are suitable with respect to the practices of the aircraft operator. This study was conducted collaboratively by the FMS manufacturers and other industry partners to achieve an acceptable industry solution.

[35] Communication, Navigation, and Surveillance.

On 26 September 2006, the CNS task force provided a proposal to improve the operation of FMSs that could be implemented via software enhancements to current FMSs. This proposal was recommended and accepted by aircraft manufacturers, FMS manufacturers and air carrier operators.

In 2009, as part of its responses, the FAA explained that because of the wide range of equipment and potential for errors at many points in the process of setting reference speeds, a single technical solution is not considered practical or effective in resolving these issues with current FMS installations. The FAA developed a policy memorandum based on the recommendations of the CNS task force that affects new airworthiness approvals for FMSs that include take-off reference speed or landing approach reference speed calculations. Advisory Circular (AC) 25-15 provides an acceptable means of compliance when augmented by the established guidelines in this policy memorandum. The policy includes the following guidance, which is supportive of the Board's recommendations:

- the FMS should provide annunciated error detection when a take-off speed is calculated or changed to a value that may affect the airplane's ability to take-off safely ;
- the FMS should contain minimum zero fuel weight (ZFW) or operating empty weight values for the airplane model on which the FMS is installed ;
- and the FMS should only allow the airplane gross weight to be calculated from valid ZFW and fuel-weight entries or accept it through automated means.

For existing FMS airworthiness approvals, the CNS task force judged that operators already have policies restricting weight entries to ZFW only. Therefore, the FAA considered it would not be necessary to retrofit the fleets to prevent gross weight entries. Also, most Honeywell flight management computer versions already incorporate a model-specific performance database and range-limited values for the respective airplane weights. If an entry is attempted outside of range limited values, the crew is appropriately notified of this. In 2011, the FAA confirmed its position with respect to the fact that a large discrepancy between the FMS displayed speeds and those being entered (33 kt for VR in the case being considered) should have led the Captain to query the speeds and resolve the difference. The FAA's opinion was that normal cross-check procedures should make pilots aware of these types of discrepancies. For existing airplanes, the FAA believed a separate alert was not necessary when the pilot overrides the FMS calculated data and did not consider this to warrant further airworthiness actions. Due to this FAA position regarding existing FMS, the NTSB classified the FAA responses to safety recommendations A-05-003 and A-05-004 as unacceptable.

The complete follow-ups of these safety recommendations are available on the NTSB's website[36].

Following the investigation conducted into the accident involving a Boeing 747 in Halifax on 14 October 2004, the TSB addressed the safety recommendation CAND-2006-007 (cf. paragraph 1.17.3.1) to Transports Canada. The subject of this recommendation was the development of take-off performance monitoring systems.

Transports Canada set up a research project in 2007. However, since April 2009, no project funding has been allocated for this project and progress has come to a standstill. As a general position, from 2006 to 2015, and again in 2017, Transports Canada indicated that there were no take-off performance monitoring systems that were suitable for use in civil aviation and that the industry was best placed to take the lead to develop a take-off performance monitoring system. This response was considered as unsatisfactory by the TSB. The TSB also noticed that in its responses, Transports Canada had never specified if the requested coordination with ICAO, FAA and EASA had been performed. The complete follow-up of this safety recommendation (still open at the date of writing this report) is available on the TSB's website[37].

In 2005, following the accident that involved a Boeing 727 in Cotonou, the BEA also addressed the safety recommendation FRAN-2005-001 (On-Board Weight and Balance Systems, cf. paragraph 1.17.3.1) to the FAA. Up to the date of writing this report, the FAA has not provided the BEA with its opinion or intention with regard to this safety recommendation.

In 2008, following the safety study conducted on the use of erroneous parameters at take-off, the BEA issued a safety recommendation (FRAN-2008-014) to develop and implement rejection and warning systems when erroneous data is inputted. Unlike EASA, the FAA did not formally respond to this safety recommendation that was formally addressed to the DGAC. As a consequence, the FAA's opinion on this safety recommendation remains unknown.

1.17.3.3 European regulations concerning EFB

A RuleMaking Task (RMT.0001) was initiated in 2006. In 2014, it resulted in the publication of AMC 20-25[38] dedicated to the Airworthiness and operational consideration for Electronic Flight Bags (EFBs).

This document gives operators the means of compliance to assess risks associated with the use of EFBs and to define the appropriate mitigations, within the scope of their management system.

The operators' attention was drawn to the need to have EFB user interfaces consistent with the other flight deck avionics applications, particularly in terms of design philosophy, look and feel, interaction logics and workflows. It was also stated that the workload of the crews must remain acceptable, which implies avoiding complex multi-step data entry tasks.

In general, it must be verified that the systems used minimise the occurrence and effects of flight crew errors and maximise the identification and resolution of errors.

[36] https://www.ntsb.gov/SAFETY/safety-recs/_layouts/ntsb.recsearch/Recommendation.aspx?Rec=A-05-003
https://www.ntsb.gov/SAFETY/safety-recs/_layouts/ntsb.recsearch/Recommendation.aspx?Rec=A-05-004
https://www.ntsb.gov/SAFETY/safety-recs/_layouts/ntsb.recsearch/Recommendation.aspx?Rec=A-05-005
https://www.ntsb.gov/SAFETY/safety-recs/_layouts/ntsb.recsearch/Recommendation.aspx?Rec=A-05-006
https://www.ntsb.gov/SAFETY/safety-recs/_layouts/ntsb.recsearch/Recommendation.aspx?Rec=A-05-007

[37] http://www.tsb.gc.ca/eng/recommandations-recommendations/aviation/2006/rec_a0607.asp

[38] AMC 20-25 published by EASA: https://www.easa.europa.eu/system/files/dfu/2014-001-R-Annex%20II%20-%20AMC%2020-25.pdf

The attention of the operators was drawn in particular to:

- ❒ calculations being conducted independently by the pilots;
- ❒ cross-checking of data by pilots;
- ❒ checking for gross errors, in particular by checking the results from other data sources.

Operators are requested to conduct evaluation tests to ensure that all the provisions mentioned in the AMC are met prior to the commissioning of the EFB. The test plan should include, as appropriate, a program of LOFT[39] sessions in the simulator and observation flights for the competent authorities.

The operators are invited to produce a final report describing the EFB system chosen and the stages for introducing it. The means of compliance adopted as well as the results of the risk studies must be specified.

Moreover, in parallel with the regulatory task that led to AMC 20-25, in 2013 EASA made a call for tenders for a study dedicated to the evaluation and use of EFBs. A report written by NLR[40] was published in January 2016 on the EASA website[41].

Lastly, another RuleMaking Task (RMT.0601) was completed with the publication of EASA Opinion 10/2017 on 18 December 2017. It aims at bringing European regulations into line with new standards and recommended practices set by the ICAO in its Annex 6 to the Convention on International Civil Aviation. The Opinion is now in the process of being adopted at the EU Commission level.

1.17.3.4 EASA management of preliminary work on OBWBS and TOPMS type systems

Before initiating a rulemaking process, EASA may seek to verify that reliable systems can actually be developed and that standards shared by the whole industry are conceivable.

With this in mind, EASA can request the creation of EUROCAE[42] working groups in order to consult the industry. As a member of this organization, EASA can lead or simply participate in the various working groups. The mandates as well as all the productions of the working groups are validated by the EUROCAE Council. At the time of writing this report, the Council consists of 18 people including one person from EASA.

Among the eight safety recommendations related to the issue of use of erroneous parameters processed by EASA between 2004 and 2012, two concerned OBWBS-type systems and three TOPMS-type systems.

EASA requested the creation of EUROCAE working groups WG-88 (OBWBS) and WG-94 (TOPMS). The reports from these two groups were forwarded to the BEA during the investigation. Their activity is summarized in the table below.

[39] Line-Oriented Flight Training.

[40] National Aerospace Laboratory, Netherlands.

[41] https://www.easa.europa.eu/system/files/dfu/EASA-Research-Rep-2014-1.pdf

[42] A non-profit organization bringing together various stakeholders in the aeronautics sector: aircraft manufacturers, equipment manufacturers, authorities, research organizations, etc.

OBWBS / WG-88	TOPMS / WG-94
Definition of the expected system	
System that displays information on the weight and balance and which the flight crew can use to check the values used for the computation of the take-off performance parameters (thrust/power and take-off speeds).	System for providing a timely alert to flight crew when the achieved take-off performance is inadequate for the given aircraft configuration and aerodrome conditions.
Related recommendations processed by EASA	
BEA (FRAN-2005-001) DSB (NETH-2007-004)	TSB (CAND-2006-007) AAIB (UNKG-2009-080) AAIB (UNKG-2009-081)
Participants	
Manufacturers, equipment manufacturers, authorities including EASA.	Manufacturers, equipment manufacturers, research institutes, authorities including EASA.
Start date of group work	
2010	2012
Initial mandate	
Establish the state of the art and study the feasibility of drawing up standards for OBWBS type systems.	Establish the state of the art and study the feasibility of drawing up standards for TOPMS type systems.
Report publication date	
9 April 2013	5 February 2015
Synthesis of work, conclusions and follow-up	
After a review of accidents and recommendations, the group studied projects already conducted on the subject. The feasibility analysis takes into account technical maturity and operational impacts. The group also proposes a cost and benefit analysis. The group concluded that the standardization of OBWBS is feasible and recommended. Technology has evolved and should provide acceptable solutions where there had been difficulties in the past. In February 2014, EASA reported that WG-88, under its chairmanship, was now tasked with developing specifications (MOPS).	Several projects led by manufacturers or research institutes are described. In its report, the group explained in particular that: ❐ A reliable system would provide a significant safety benefit. ❐ No TOPMS has been certified. ❐ It is difficult to define common standards because of the lack of availability or standardization of the parameters necessary for the proper functioning of the system. These parameters include the aircraft model, the moment at which the crew should be alerted, the runway conditions, the database of the airport environment. ❐ Progress in technology and standardization is being made.

OBWBS / WG-88	TOPMS / WG-94
The Agency included a rulemaking task RMT.0116 entitled "*Real weight and balance of an aircraft*" in the European Plan for Aviation Safety (EPAS) 2018-2022. The objective of this task is to consider the possibility of requiring commercial air transport aeroplanes to be equipped with an OBWBS. The MOPS produced by WG-88 work will be taken into account, and a regulatory impact assessment will be performed to compare the expected safety benefits brought by an OBWBS against its costs and other potential impacts. At the end of 2015, EUROCAE called for the participation of WG-88 in the development of MOPS. This second phase started in 2016. EASA says that, since 2015, the chairmanship of EUROCAE WG-88 has been taken over by industry, and that it is therefore less able to control actions and timelines. In the Preliminary Impact Assessment (PIA) completed in 2016, EASA stated that the rulemaking task (RMT.0116) was to start in 2017 based on the findings of WG-88. In the European Plan for Aviation Safety (EPAS) published by EASA in January 2016, the decision regarding RMT.0116 was scheduled for 2019. The version published in January 2017 postponed this deadline to 2021 while the 2018 version now provides for a decision in 2022. EASA informed the BEA that these postponements are due to the pending deliveries from EUROCAE WG-88.	In its report, WG-94 recommends not to initiate standardization activities of TOPMS type systems. However, it proposes that this situation be reviewed in the medium term (3 – 5 years after the initial study). In April 2015, EASA stated that the industry needed to continue its efforts regarding technical solutions and that it would follow them up. EASA confirmed the possibility of reactivating a EUROCAE working group at a later date.

1.17.3.5 EASA analysis of other systems under development

On several occasions, notably in 2011 and 2014 in response to safety recommendation FRAN-2008-014, EASA stated that systems currently under development could help detect errors when entering take-off parameters (mutually inconsistent data, data too far from the usual values, missing data). EASA specified that their effectiveness was, however, not yet known and that the agency needed to study these features further before being able to certify them or make them mandatory.

During the investigation of the F-GUOC serious incident, the BEA asked EASA for the available results from this study. EASA replied that it had not carried out a review of existing systems of this type.

In this reply, the agency recalled that such systems capable of detecting errors in data entry were also suggested in a study by the Australian Transport Safety Bureau (ATSB).

EASA added, however, that Boeing had already drawn attention to the limitations of such systems, in response to the following recommendation[43] made to it by the TAIC in 2003:

"*Implement a FMS software change on all various Boeing aircraft models that ensures any entries (such as V speeds and gross weight) that are mismatched by a small percentage are either challenged or prevented*".

The limitations identified by Boeing at the time included:

- the possibility that the reference speeds used by the crew were actually based on a weight incorrectly entered in the FMS;
- the risk of nuisance warnings due to frequent differences between the reference speeds and the speeds calculated by the EFB, with the warnings likely to lower the crew's confidence in these protection systems.

Nevertheless, Boeing indicated that they were exploring the possibility of checking that the manually-entered VR speed was not significantly lower than that automatically calculated by the FMS.

Furthermore, in its response to the BEA during the F-GUOC serious incident investigation, EASA mentioned Airbus' development of the Take-Off Securing function (TOS)[44] (cf. paragraph 1.18.9). EASA explained that if discrepancies are detected between the speeds entered manually in the FMS and those calculated by the system, the crew is alerted by a message on the FMS display unit.

EASA stated that Airbus provided the ATSB with the results of a simulation of the operation of the TOS based on the parameters recorded during an accident on an A340. According to this simulation, the "*TO speed too low*" warning would have been activated if the TOS function had been installed.

Despite this, EASA concluded that although some errors are actually detected, it is still not possible to estimate the proportion of events that would be avoided.

[43] Recommendation 047/03 as part of an investigation into a Boeing 747 accident in Auckland on 12 March 2003.

[44] Even if they are mentioned in the WG-94 report, the Airbus TOS functions, in particular TOS1, do not fall within the scope of this working group insofar as they do not concern the actual performance of the aeroplane after application of thrust.

1.18 Additional information

1.18.1 Witness statements

1.18.1.1 Captain (PM)

Preparation on ground

The Captain had returned on Sunday, 17 May from a rotation of nine days which took him to Tahiti. On Thursday, 21 May, he was scheduled for simulator training but the session was finally cancelled. He arrived on Friday, 22 May (the day of the incident flight) having had an interrupted night's sleep, a consequence of remaining jet lag, but he considered that he was correctly rested. He left home 3 h 30 min before the off-block time and arrived at the flight operations office 2 h 45 min beforehand. He had time to read the 777 sector documents. He saw the Relief Pilots arrive. The Co-pilot, PF on this flight, arrived just after and all four began to prepare the flight in the flight planning room. One of the Co-pilots dealt with the NOTAM, a second dealt with the Aircraft Company Note and he dealt with the weather. Once completed, each made their briefing. Due to the expected presence of thunderstorms on arrival in Mexico, the crew decided to take extra fuel. On the Flight Preparation screen, the proposed payload was incompatible with the aeroplane. The crew called the Dispatch Office because with the planned payload of 114 tonnes, maximum ZFW was exceeded. The OFP gave 93 tonnes and they were told to rely on this. They left for the aeroplane and quickly went through the security checks. They arrived around 11:00 am for an off-block time of 12:15 local time. The flight coordinator was not there. The Dispatch Office and the ground staff confirmed the load of 93.3 tonnes which corresponded to that of the OFP.

Flight preparation in cockpit

The Captain gave the order to restart fuelling. The crew flight preparation was standard. The Captain took the TOW from the OFP to which he added the difference between the fuel load specified on the OFP and that decided on by the crew. He did his calculations, found 343 tonnes but entered 243 tonnes in the OPT. He read out the left column, then the right column and lastly the lower part of the OPT (runway, taxiways, weights, speeds, reduction) and the Co-pilot (PF) replied that he had the same results. They had no misgivings about the "*Take-off Cards*". When they started to enter the speeds, he noticed a big difference between V1 and the reference speed(s) displayed and deduced from this that there was an inconsistency. The Co-pilot told him that refuelling was not yet finished and that this could explain the problem. They waited for the end of refuelling. Meanwhile, the other two Co-pilots had come back. The Final Loadsheet arrived and he underlined the ZFW and the TOW which were consistent with the values of the FMS. The Captain circled the TOW. When the crew wanted to enter the take-off speeds again, the reference speeds were no longer displayed. The Captain decided to enter the ZFW again as this deletes the data. They entered the data again but still did not get the reference speeds. Before entering the data, the Co-pilot (PF) redid a calculation on the OFP but he made an error of 100 tonnes and said "*it corresponds*". The Captain compared the Final Loadsheet (correct) with the FMS data (correct) but not with the OPT (erroneous). In the absence of the reference speeds, the speeds from the OPT were entered and they left.

Taxiing and take-off

The crew lined up via T12 instead of T11 and did not perform a rolling take-off. The aeroplane accelerated. The Captain called out V1 then VR. The PF's rotation input was gentle. The aeroplane lifted off but did not climb. The Captain looked outside. The Co-pilot (PF) eased the column forward. The Relief Pilot in the central position said "*TOGA*". The Captain then felt a good acceleration of the aircraft. The Captain was afraid of striking the buildings in front and was concerned about the vertical speed. He wanted to order the retraction of the landing gear when the vertical speed was positive but not at just any time. Everything happened very quickly. The other Relief Pilot monitored the speed and called out aloud for flap retraction. Once the vertical speed had become clearly positive, the Captain called out for the retraction of the landing gear. The climb was smooth. The speed was above the VLS and the pitch below the PLI. The aeroplane accelerated. At around 5,000 ft, they changed the altimeters to the standard setting and then carried out the check-list. Then the Co-pilots mentioned the possibility of a tailstrike but he excluded this as he was the only one to have looked out of the window and the height was about ten metres. They then evoked pitot static system problems and loading problems (one Relief Pilot had seen a gap between two pallets). Finally the Co-pilot (PF) picked up his OFP again and saw his error of 100 tonnes. He shared the information.

The four members of the crew felt good even if the Co-pilot (PF) was "*shaken*". The crew continued the climb and passed FL100. The Captain told the Co-pilot (PF) to leave his seat and one of the Relief Pilots replaced him. The Captain became the PF for half the flight.

The four members of the flight crew worked together in an optimal way. The Captain was then replaced by the second Relief Pilot. He was absent for approximately 1 h 15 min with a nap of 20 minutes. When he came back to his seat, the Relief Pilot in the right seat went for a rest and the other Relief Pilot in the left seat took the right seat. The arrival in Mexico City was normal. After arriving at the airport apron, the Relief Pilots went to see the tail of the aeroplane and confirmed the absence of a tailstrike. The four flight crew went to the hotel and discussed the event. They noted that the Captain and the Co-pilot had entered the same incorrect weight and that the cross-check only confirmed the result.

Saturday morning, they all met up to write the Air Safety Report (ASR). In the end, all the crew members returned to France as passengers.

The Captain could not explain how he had not detected the inconsistency between the V2 and the weight because he said he knew the orders of magnitude. For example, he said that for the weight of the day, V2 was about 180 kt. He added that the absence of reference speeds and the interruption in tasks were contributing factors.

His feeling was that there was no panic during take-off. The Relief Pilot who was in the central position had a view of everything. Only the Captain had the notion of height. At the end of the runway, they were climbing. If there had only been two pilots in the cockpit, they would have had a problem.

In his interview, the Captain provided the following clarifications:

- he confirmed that he thought he had entered 343 tonnes but that he entered 243 tonnes;
- he did not verbalize the weight data before the comparison (in general and for this incident) ;
- from the moment the "*Take-off Cards*" were compared, he considered that there were no errors on the "*Take-off Cards*";
- in the CDU of the FMS, he checked with the Co-pilot that the values called out were equal to the values entered;
- when the Final Loadsheet arrived, he checked that the data of the aeroplane systems was consistent with that of the Loadsheet. He did not check the Take-off Card. He compared the TOW (load sheet) with the TOW (FMS). He did not compare the load sheet with the EFB (e.g. the TOW) because the data had not changed;
- this was the first time he noticed such a big difference between the reference speed values and the speed values to be entered;
- there was no system protection when the wrong speeds were entered;
- he did not remember hearing a warning or that the shaker was activated;
- he did not take the controls because the PF was accurately piloting and the thrust was TOGA;
- the decision to continue the flight was a shared one but the FORDEC[45] was shortened;
- the crew talked a great deal about the event on arrival. The Captain wanted to avoid discussing it during the flight so as not to disrupt the flight;
- the new Operational Flight Plan (OFP) has been in effect since February 2015.

[45]FORDEC is the crew method of decision-making used at Air France.

1.18.1.2 Co-pilot (PF)

Preparation on ground

The pilot had had an excellent night's sleep before the day of the flight. He arrived just over two hours before the scheduled take-off time at 12:25 pm local time in the flight planning rooms for a Paris CDG-Mexico cargo flight. The Boeing 777-F is the cargo version of the 777 ''*betwee*'' the 200 and 300 series. The Co-pilot (PF) was the fourth member of the flight crew to arrive and the other crew members were introducing themselves. He took the items of the day and noticed that the weight of the day was 20 tonnes from the MTOW of the day. He noticed that the estimated weight in one of the flight file sections (LSFW) gave a load of 114 tonnes. This was impossible because on the OFP, they had a load of 94 tonnes and were already close to the limitations. They called the Dispatch Office, who told them to take the weights of the OFP. He therefore considered that they were aware that the weight was high and close to the limits. The crew then discussed the fuel to take on-board and decided to take 107.3 tonnes of fuel.

Flight preparation in cockpit

They then left for the aeroplane and found that loading had finished. The agent told them the load was 93.3 tonnes which was a little less than the OFP and the crew kept the scheduled 107.3 tonnes of fuel.

He was PF for the leg. Another Co-pilot carried out the exterior walkaround and the 3rd Co-pilot checked that the load was safely in place. The crew validated the final load and ordered refuelling to be finished. He entered the route in the FMS and chose the calculation elements for the Take-off Card (with a load of 93.3 tonnes). He added the block fuel weight (107.3 tonnes) to the ZFW (235.7 tonnes) and got 243 tonnes instead of 343 tonnes. In the EFB, he entered 243 tonnes and entered the other elements recorded with the ATIS (choice of runway).

The Captain did the same. The calculation was then started. The Co-pilot (PF) does not know if he verbalized 243 tonnes (instead of 343 tonnes). The results were compared: runway, wind, pressure, flaps and speeds. The results obtained were the same: the Captain also called out a weight of 243 tonnes.

The other two Co-pilots came back to the cockpit. The Co-pilot (PF) performed his briefing and said in particular "*we are heavy*". There were no questions after the briefing. At this point, refuelling was still in progress.

The Captain decided that they could enter the values because he had received the Final Loadsheet. The Captain only gave him the load value of the Final Loadsheet. In the margin of the OFP, the Co-pilot (PF) then calculated the DOW + PLD[46] = ZFW + fuel (106.6 tonnes) = 241.5 tonnes instead of 341.5 tonnes. He forgot to carry over a value. He then turned to his OPT and said "*it's consistent*". The Captain underlined the characteristic values on the Final Loadsheet (ZFW, TOW) and circled the MACTOW[47] and then the Co-pilot (PF) entered the data: balance, Flex flap setting. He then started to enter the speeds: the Captain gave him the V1, he entered the V1.

[46]Dry Operating Weight + PayLoaD.

[47]Position of centre of gravity on take-off expressed as the mean aerodynamic chord take-off weight.

The Captain said that there was too great a difference between the V1 and the reference speeds calculated by the FMS. The reference speeds were approximately 20 kt above the calculated speeds.

The Co-pilot (PF) referred to the fact that the refuelling had not finished. The crew suspended the data entries thinking that it was necessary for the fuel probes to stabilize. They performed other tasks. Once the refuelling was finished, they resumed entering the data but the reference speeds were no longer displayed. They then decided to re-enter all the data (ZFW, T° Flex, balance, flap setting, etc.). Re-entering the ZFW overwrote the previously entered data. The crew expected to see the reference speeds again but they had disappeared. A priori the FMS CDU ON/OFF button that displays the reference speeds was set to ON by default.

The crew entered the speeds.

They then make a mental short-cut: the refuelling was finished and the system did not prohibit the speeds from being entered so it had to be alright.

The error was thus made in two steps: firstly, they noticed a difference between the speeds to be entered and the reference speeds. When they started re-entering the data on completion of the refuelling, the reference speeds had disappeared and the system did not prohibit the take-off speeds from being entered.

The two Co-pilots behind said nothing, for them everything was normal.

Taxiing and take-off

They taxied towards T12 instead of the scheduled T11. This left them with a remaining runway margin of 3,600 m (given by the ATC) instead of the planned 3,400 m.

The Co-pilot (PF) initiated the take-off (TOGA switch) and the thrust reference was correct. The acceleration seemed normal. V1 then VR were called out. He pulled gently on the control column because he was always apprehensive about a tailstrike. The aeroplane then gradually adopted the take-off pitch. The aeroplane rose and then sank just after (no touchdown). The feeling of sinking seemed abnormal to him. He eased the column forward and kept the aeroplane horizontal. He was surprised for a brief moment. He thought for two seconds and then heard the TOGA callout from the Relief Pilot in the middle. The callout brought him out of his thoughts. He placed his hand on all the power levers and pushed them forward while also pressing the TOGA switch. He immediately felt a major acceleration and adjusted the pitch to climb. All the members of the crew were monitoring him because he had to fly between the VLS and the PLI which limits the pitch. The Co-pilot (PF) said that he continuously managed to stay at a speed above VLS. The aircraft was in a clean configuration at an altitude of around 5,000 ft. On the PFD speed indicator, the "*5*" index[48] was visually high. Once the aeroplane was in its clean configuration, they changed to the standard altimeter setting and then the crew performed the After Take-off check-list. The Co-pilot wondered what could have happened, he had had the impression that "*the aeroplane was not flying*". The crew evoked among other possibilities, the problem of a tailstrike, or a wingstrike. The Co-pilot looked at his OPT and saw the weight calculation error. At FL200, he was relieved by his colleague behind him after having had "*a good fright*". The crew discussed the entry error. The flight continued and the landing in Mexico City went smoothly. They talked together at the hotel but the next day he did not feel well. Finally, the decision was taken to return to France as passengers which was a relief to them.

[48]This index represents, on the PFD speed band, the maneuvering speed associated with flap configuration 5 for the extension or retraction of the flaps.

In addition, he said that:

- regarding the ON/OFF button to display reference speeds, he could not remember if they had pressed it;
- he estimated that they flew over the end of the runway at a height of 50 ft above the ground;
- the clear acceleration after applying TOGA thrust was correlated with the speed trends;
- there was no warning during the take-off;
- after arriving in Mexico City, the four flight crew members drafted the ASR;
- there is a V1 min and VR min but they had not had the corresponding message. He does not remember having already had the V1 min or VR min message on other flights;
- at the time of take-off, he was not watching the Flight Director indications;
- he knew the speed orders of magnitude according to weight;
- he has never before been confronted with problems of disappearing reference speeds.

1.18.1.3 First Relief Pilot

Preparation on ground

The first Relief Pilot looked at the OFP. There was a problem with the payload, it was not compatible with the aircraft capacity. The Captain contacted Dispatch about this problem. The crew was aware of the heavy weight of the aircraft. They all agreed to take 12 tonnes of additional fuel.

The aircraft was already loaded when they arrived at the aircraft.

The first Relief Pilot went to the rear of the aircraft to check the load. There was no change to the load.

He and the other Relief Pilot were not present when the parameters were inserted the first time.

He had the impression that the Captain and the Co-pilot (PF) worked together in an optimal way. Everything seemed very business-like and the Captain gave the impression of being rigorous in his work.

When the Final Loadsheet arrived, the Captain announced the payload. The Co-pilot (PF) made the calculation and announced "*243 tonnes it is consistent with the EFB*". He made a mistake of 100 tonnes. The first Relief Pilot saw the Co-pilot (PF) move to turn towards the EFB. Nobody saw the mistake. The Captain had underlined 343 tonnes on the Final Loadsheet. The Captain folded and put away the Final Loadsheet.

The first Relief Pilot followed the problem of the reference speeds. He was there when the Captain and the Co-pilot (PF) entered ZFW. The crew's operating mode seemed to be normal. From his seat he could not see the central screens which display the FMS.

Taxiing and take-off

The safety briefing was very good but the Captain did not mention that TOGA thrust was available. Everything went well from the application of take-off power to the rotation.

After the rotation, once in the air, the Co-pilot (PF) eased the stick forward. This surprised the crew. He talked to the other Relief Pilot and said, "*Something is not right*". Both Relief Pilots looked outside, through the lateral windows. They noticed that the aircraft was not climbing but was accelerating.

The second Relief Pilot bent forward and looked at what was happening. It was at this instant that he (the second Relief Pilot) announced TOGA.

The Captain announced a positive vertical speed and controlled landing gear retraction. The first Relief Pilot looked forward at the PFD and spoke about the speed and the PLI. During the initial climb, he talked with the other Relief Pilot about the possible causes. They considered a probe problem and they also talked about tailstrike. They believed no tailstrike occurred.

The Co-pilot (PF) understood the error and showed his EFB to the rest of the crew. The first Relief Pilot offered to replace him, as he seemed to be affected.

In Mexico, the crew talked about the event and wrote the report.

1.18.1.4 Second Relief Pilot

<u>Preparation on ground</u>

He was not tired.

He did some calculations on his OFP taking into account the fuel he wanted at landing. He found a take-off weight of 340 tonnes and gave his OFP to the Co-pilot (PF).

The Captain noticed a payload of 114 tonnes in the estimated weight section of the flight file, which was not consistent because it would give a ZFW greater than the maximum ZFW. The Captain called Dispatch who told them to take the OFP payload which was consistent.

When they arrived at the aircraft, everything was ready. They were not in a hurry.

The second Relief Pilot did some fuel calculations and discussed his results with the other Relief Pilot who did the same kind of calculation. This resulted in consistent results.

He carried out the exterior walkaround in about 10 to 15 minutes. The aircraft was already loaded.

He came back on board and everything seemed calm and the crew nice and professional.

He was not present when the Captain and the Co-pilot (PF) first attempted to enter take-off speeds. The Captain had detected a 20 kt difference that was not normal.

When they attempted to enter the speeds a second time, all of the crew members were present. The reference speeds were not displayed. The Captain and Co-pilot (PF) pushed the ON/OFF button several times to try to display them. They tried to find why they had disappeared but did not understand why this had happened.

The two Relief Pilots also tried to understand without success. The second Relief Pilot had never seen this.

The Captain decided to re-enter the ZFW with the Co-pilot (PF) crosschecking. The reference speeds were still not displayed, which was unusual. The criterion was to see that the FMS accepted the entered speeds.

The second Relief Pilot had no specific misgivings about the Take-off Card. The performance calculation was done by the Captain and the Co-pilot with a crosscheck. The second Relief Pilot had not had the Take-off Card and did not know it was printed.

<u>Taxiing and take-off</u>

There was nothing noteworthy before applying take-off power. He did not feel anything unusual during the take-off run and the rotation. The aircraft's nose rose normally. He had the impression that the lift-off was slow and the aircraft sunk and levelled off. He said to himself that the aircraft was not climbing or accelerating, and decided to announce TOGA. He had the impression that there were three seconds between the lift off and his announcement, and that one second later the Co-pilot applied TOGA power. He felt a strong acceleration and noticed a progressive climb. The first Relief Pilot helped the Co-pilot (PF) monitor the speed.

During the climb both Relief Pilots wondered about a possible anemometric, balance or loading problem. The Co-pilot (PF) said, "*I've found it, it is huge*" and showed his EFB.

The crew mentioned the possibility of a tailstrike but they were sure that it was not the case. At FL200, the other Relief Pilot offered to replace the Co-pilot (PF) which the latter accepted.

At Mexico, they wrote a report together that reflected what happened: the Co-pilot (PF) had piloted well, the second Relief Pilot announced TOGA which was correctly applied by the Co-pilot, the Captain paid attention to the landing gear and the first Relief Pilot monitored the speed.

In addition, he said in his statement that after the start-up during the flight of the event, he was a little bit surprised because the Captain called for Flaps 5, whereas he was expecting Flaps 15. He reassured himself by saying to himself that the 777 cargo was like a 777-200 but with 777-300 engines. He did not have any misgivings about the Take-off Card.

1.18.2 OFP, Take-off Card and Final Loadsheet used for preparation of event flight

The Co-pilot's OFP, the Take-off Card and the Final Loadsheet are shown below:

4 **AF 6724 LFPG/MMMX 22May2015/1015z** Main OFP (Long copy #2) Tri 142 D **released: 22May/0711z** OFP 4/0/1 AF/

FLIGHT SUMMARY M08

OFP 4/0/1 22MAY2015/07:02

AF6724		+2		FGUOC	B777-200/GE90-110B	
ATC:AFR6724		LFPG/CDG 1015	10.09 1035 10.25		CRZ SYS VRB	50/83/50
22MAY15	2040	MMMX/MEX 2149 .... 2134			GND DIST 5188	
		-5			AIR DIST 5294	
		STA 2135			AVG W/C H009	
					AVG ISA P06	
					F-F FACTOR +2.9	

LIMITATIONS 4+0 H_2O 50%

		ESTIMATED	ACTUAL	STRUCT	MAX DAY	DELTA	OPS FUEL	
141.6	DOW	141575	......				FINAL 8.2	MACTOW
93.3	PLD	93.3 94130	+......		106540		ALTN +.3.9.	PAX
	ZFW	235705	=......	248115		12410	EXTRA +......	
234.9	FDEST	F	+......				FDEST =......	1.7
106.6	LAW	245950	=......	260815	....	14865		
	TRIP	93849 F	+......				TRIP +......	
241.5	TOW	339799	=......	347451	....	7652		
	TAXI	660 F	......				TAXI +......	
	FUEL	104754	107.3	145016		40262	BLOCK =......	

PLD+FUEL 205876 ......

FUEL SUMMARY Σ 0.795

TRIP	93849	....	1059	....	
CONT 3%	1707	....	0012	MMMD	7.1
ALTN	3898	....	0030	MMQT	3.2
FINAL	3143	....	0030		10.3
MINI T/OFF FUEL	102597	....	1210		235.7
- HOLD	1015	....	0010		246.0
- OPN	482	....	0003		93.9
T/OFF FUEL	104094	....	1224		
TAXI OUT	660	....	0020	TAXI IN: 495KG / 0015MIN	
BLOCK FUEL	104754	....			
PIC EXTRA	.....	....	LOSS FOR EXTRA FUEL 126EUR/T		339.9
TOTAL FUEL	.....	....			.7

STATISTICS 1/6,3 N / F30 / 2800 (45')

NIL N-1 / F20 / 340.6

OPERATIONAL IMPACTS 235.7

TOW UP 1000 KGS		TRIP P 0164 KGS	TIME P 0001	104.9
TOW DN 1000 KGS		TRIP M 0348 KGS	TIME P 0001	
LAW UP 1000 KGS		TRIP P 0351 KGS		107.9
FL CHANGE	UP FL1	TRIP P 0236 KGS	TIME P 0006	
FL CHANGE	DN FL1	TRIP P 0496 KGS	TIME P 0003	
SPD CHANGE	CI0	TRIP M 0186 KGS	TIME P 0008	
SPD CHANGE	CI150	TRIP P 0523 KGS	TIME M 0006	

PIC SIGNATURE

CAPTAIN NAME: SIGNATURE:

[redacted]

- Traversées de piste.
- 17000 → 250 kt
- FL Elevé
- ⚠ MMMX
- TS → WS
- Terrain
- Alt → Vp → Disabate
- VARR ?
- Serie décalé
- Y
- CRM
- ATC CLR "APPCH VIA.."
- No Flaps > FL200 !!!

LAW 248
VREF 146
Alt' 6T/50'
A/B3 3412m
A/B4 2873m
LDA 3500m

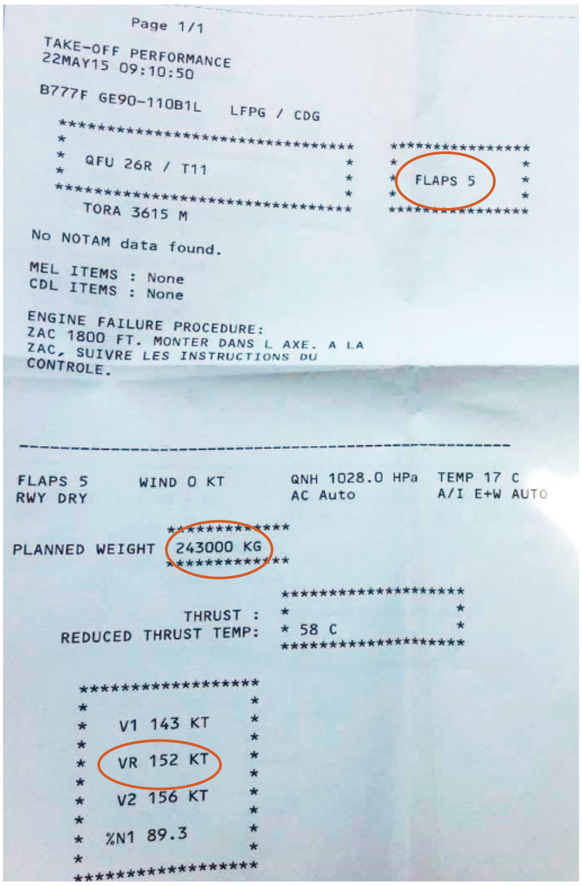
13,1 / 7,1 / 6,0

13,6 / 13,1 / 234,9 / 248.0

10.3 / 1.7 / 12.0 / 235.7 / 247.7 / 94.6 / 342.3 / .7 / 343.0 / 235.7 / 107.3

© AirFrance Page 15 of 60 Generated at 22May/0716z

Co-pilot's Operational Flight Plan



Page 1/1
TAKE-OFF PERFORMANCE
22MAY15 09:10:50

B777F GE90-110B1L LFPG / CDG

QFU 26R / T11

FLAPS 5

TORA 3615 M

No NOTAM data found.

MEL ITEMS : None
CDL ITEMS : None

ENGINE FAILURE PROCEDURE:
ZAC 1800 FT. MONTER DANS L AXE. A LA
ZAC, SUIVRE LES INSTRUCTIONS DU
CONTROLE.

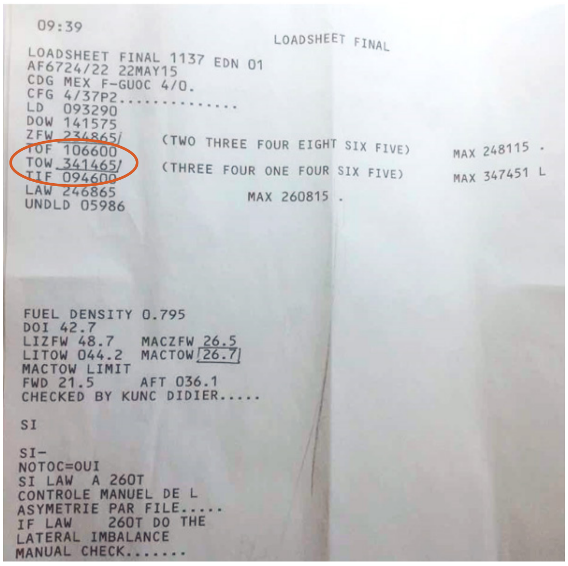
FLAPS 5 WIND 0 KT QNH 1028.0 HPa TEMP 17 C
RWY DRY AC Auto A/I E+W AUTO

PLANNED WEIGHT 243000 KG

THRUST :
REDUCED THRUST TEMP: 58 C

V1 143 KT
VR 152 KT
V2 156 KT
%N1 89.3

Take-off Card



09:39
LOADSHEET FINAL

LOADSHEET FINAL 1137 EDN 01
AF6724/22 22MAY15
CDG MEX F-GUOC 4/0.
CFG 4/37P2..............
LD 093290
DOW 141575
ZFW 234865/ (TWO THREE FOUR EIGHT SIX FIVE) MAX 248115 .
TOF 106600
TOW 341465/ (THREE FOUR ONE FOUR SIX FIVE) MAX 347451 L
TIF 094600
LAW 246865 MAX 260815 .
UNDLD 05986

FUEL DENSITY 0.795
DOI 42.7
LIZFW 48.7 MACZFW 26.5
LITOW 044.2 MACTOW 26.7
MACTOW LIMIT
FWD 21.5 AFT 036.1
CHECKED BY KUNC DIDIER.....

SI

SI-
NOTOC=OUI
SI LAW A 260T
CONTROLE MANUEL DE L
ASYMETRIE PAR FILE.....
IF LAW 260T DO THE
LATERAL IMBALANCE
MANUAL CHECK.......

Final Loadsheet

It can be noted that:

- on the OFP, in the Limitations part, there is a weight calculation whose final result is 241.5 tonnes instead of 341.5 tonnes;
- the Take-off Card gives a weight of 243 tonnes, a rotation speed of 152 kt and a 5° flap configuration;
- the Final Loadsheet gives a TOW of 341,465 kg.

1.18.3 Take-off parameters calculated by the OPT from the correct weight and the erroneous weight

Air France recalculated from the OPT, the performance at take-off in the conditions of the day with the erroneous weight entered by the crew (243 tonnes) and the correct weight (343 tonnes).

	Calculation with erroneous weight Weight of 243 tonnes	**Calculation with correct weight** Weight of 343 tonnes
V1	143 kt	167 kt
VR	152 kt	175 kt
V2	156 kt	179 kt
Reduced thrust temperature	58 °C	37 °C
Flap configuration	5 °	15 °
Thrust	89.3% of N1	98.5% of N1

1.18.4 Similar incidents on Boeing 777-300

A DSB investigation report[(49)] deals with a serious incident very similar to that of the F-GUOC, that of the PH-BVG on 7 July 2013 in Schiphol (Netherlands). This report also mentions another similar incident that occurred on 31 August 2009 involving the same operator.

The complete DSB report is available in Appendix 3 of this report.

In both events, as in the case of the serious incident involving F-GUOC:

- a weight value of 100 tonnes below the actual weight was entered in the EFB;
- the take-off speeds calculated by the EFB from this erroneous weight value were entered in the FMS;
- the V SPEEDS UNAVAILABLE message did not sufficiently alert the crews, who in both cases continued the take-off;
- take-off occurred at a speed significantly below that corresponding to the actual weight.

The DSB stated in its report that:

- the actions taken by the operator after the 2009 incident were not sufficient to prevent a similar event four years later;
- the 2009 internal investigation of the operator had concluded that the adjustment of the procedures was not the solution for preventing such incidents.

The DSB concluded that particular emphasis should be placed on the prevention of entry errors. It recalled that at the time of the incident in 2013, no progress had been made on this subject, despite the many recommendations calling for the development of gross error detection systems in performance calculations.

(49) https://www.onderzoeksraad.nl/nl/media/attachment/2018/7/10/3759582bd5c0ovv_kwartaalrapportage_luchtvaart_kw_i_2016_en.pdf

Following the serious incident in 2013, the operator decided to replace the OPT with an external performance calculation system called LINTOP[50] which warns the crew when a clearly erroneous weight is used during the take-off performance calculation.

[50] Cf.paragraph 1.18.7.

The operator also issued a recommendation to Boeing to improve the wording of the V SPEEDS UNAVAILABLE message. Lastly the DSB asked Boeing if the display, explanation, and meaning of this message could be improved.

Boeing replied that no change was planned for the V SPEEDS UNAVAILABLE message.

1.18.5 "Use of erroneous parameters at take-off" study published by the BEA in 2008

The BEA commissioned the LAA to carry out a study dealing with the problem of using erroneous parameters at take-off, which was published in 2008:

https://www.bea.aero/etudes/use.of.erroneous.parameters.at.takeoff/use.of.erroneous.parameters.at.takeoff.pdf

The study took into account:

- twelve incidents or accidents which had been the subject of reports, from 1990 to 2006 involving the following aircraft: Boeing 747, 767, Airbus A321, A330, A340 and Embraer ERJ190;
- Boeing and Airbus publications on take-offs with erroneous speeds;
- observation flights made by Human Factor specialists.

The conclusions of the study were as follows:

- The variety of events showed that the problem of determining and using take-off parameters was independent of the operator, the type of aircraft, equipment and method used.
- Errors relating to take-off data were common. They were generally detected by compliance with procedures or by personal methods, such as mental arithmetic.
- The occurrences analysed revealed that the dysfunctions corresponded to errors originating from the calculation of take-off parameters or the entry of speeds in the FMS, but not from the entry of the weight in the FMS.
- Verifications of the calculation of take-off parameters can be ineffective because they consisted in verifying the entry of the values but not the accuracy of the values themselves.
- Weight values manipulated by crews before the flight can be available, according to the documents or the software, under various denominations or acronyms and in different units and formats for the same datum, which makes their memorisation difficult.
- Checking data on multiple media is often ineffective. It is limited to element-by-element comparisons. In particular, there is no joint comparison between the take-off weight values shown on the Final Loadsheet, on the Take-off Card or its electronic equivalent, and in the FMS.

- Pilots' knowledge of orders of magnitude of parameter values determined by empirical methods was the strategy most often cited to avoid significant errors. However, this knowledge decreases with the use of precise calculations for optimizing parameters.
- The FMS studied allowed entry of inconsistent weight and speed values or values outside the operational limitations of the aircraft concerned. Some systems accept the omission of entering speeds, without warning the crew of this.
- The actual availability of the Final Loadsheet shortly before departure requires the crew to perform a large number of tasks, and to enter and display parameters under strong time pressure.

The study identified the following areas for improvement:

- reinforcement of software checks during performance calculations and data entry in the FMS;
- mandatory implementation of a warning system by the FMS when an inconsistency is detected between the weights and the speeds entered;
- establishment of an autonomous aircraft system, independent of the crew, calculating the weight and balance and therefore the take-off speeds;
- homogenization of all the media used by the crew to calculate performance and enter parameters;
- systematic association of weight data with speed data during checks;
- simultaneous check of data from various media: FMS, EFB/Take-off Card, Loadsheet;
- reinforcement of knowledge of and/or access to weight - speed orders of magnitude;
- reinforcement of the training of crews in emergencies relating to take-off with erroneous parameters.

The study specifies that the solution is not to implement all of these possible barriers. The implementation of all the barriers, in particular the procedural barriers would in fact substantially increase the workload in the preparation phase.

Two safety recommendations were formally made on the basis of this study (cf. paragraphs 1.17.2.2 and 1.17.3.1):

- to the DGAC, concerning the oversight of operators (FRAN 2008-022);
- to EASA, through the DGAC, concerning gross error detection systems (FRAN 2008-014).

The 2005 BEA recommendation regarding the OBWBS (FRAN-2005-001) was also recalled on this occasion.

1.18.6 Other international studies

a) ATSB study

In 2009, the ATSB published a 100-page study entitled **Take-off performance calculation and entry errors: A global perspective**. It is available at the following address:

https://www.atsb.gov.au/media/2229778/ar2009052.pdf

Here are some excerpts from its conclusions:

Overall, the study determined that these types of errors occur irrespective of the airline, the aircraft type, the equipment, and the data calculation and entry method used.

Unfortunately, the above examples are not isolated and despite improvements in automated cockpit systems and robust operating procedures, these errors continue to occur.

Despite advanced aircraft systems and robust operating procedures, accidents continue to occur during the take-off phase of flight. The take-off is recognised as one of the most, if not the most, critical stage of flight, as there is limited time and options available to the flight crew for managing abnormal situation such as insufficient airspeed.

Experience shows that the calculation and entry of erroneous take-off performance parameters have many different origins. The safety factor analysis of the 20 international occurrences showed that many factors have been identified at all levels of influence.

Due to the immense variation in the mechanisms involved in making take-off parameter calculation and entry errors, there is no single solution to ensure that such errors are always prevented or captured. These include: appropriate crew procedures, especially those involving cross-checking; aircraft automation systems and software design involving the entering and checking of data; the provision of, and design of flight documentation and performance charts; and adequate crew pairing that accounts for aircraft-type experience for all crew operating the aircraft. At the same time, pilots need to ensure procedures are followed even when faced with time pressures or distractions.

The results of this study, and that from other related research, have recognised that these types of events occur irrespective of the airline or aircraft type, and that they can happen to anyone; noone is immune. It is imperative that the aviation industry continues to explore solutions to firstly minimise the opportunities for take-off performance parameter errors from occurring and secondly, maximise the chance that any errors that do occur are detected and/or do not lead to negative consequences.

b) NASA Study

In 2012, NASA published an 88-page study entitled **Performance Data Errors in Air Carrier Operations: Causes and Countermeasures**. It is available at the following address:

http://human-factors.arc.nasa.gov/publications/NASA_TM2012-216007.pdf

Here are some excerpts from its conclusions:

"our study suggests that more accidents are likely to occur unless existing measures to prevent and catch these errors are improved and new measures developed.

Most of the errors we examined could in principle have been trapped by effective use of existing procedures or technology; however, the fact that they were not trapped anywhere in the chain of developing and applying the data indicates a need for better countermeasures. Existing procedures are often inadequately designed to mesh with the ways humans process information and their associated vulnerability to error—and procedures often fail to take into account the ways in which information flows in actual flight operations and the time pressures experienced by both pilots and ground personnel.

Because data entry errors are so prevalent, we suggest that airlines employ automated systems (feasible with current technology) that eliminate the need for manual data entry wherever possible in the process.

Without effective countermeasures, errors will inevitably creep into the data process because of human cognitive vulnerabilities and operational exigencies.

An autonomous onboard weight-and-balance sensing system—as an independent source of information—can serve as an effective cross-check for the weight and balance values derived from the performance data process.

Regardless what approach to verification is taken, weight and balance information—as well as performance parameters derived from this information—should be compared between independent sources.

FMS interface design can be improved to prevent some types of data entry errors.

One cross-check that can be readily incorporated in airline procedures is a pre-departure comparison between the preliminary (flight-planned) and the final weight/balance data".

1.18.7 LINTOP performance calculation system

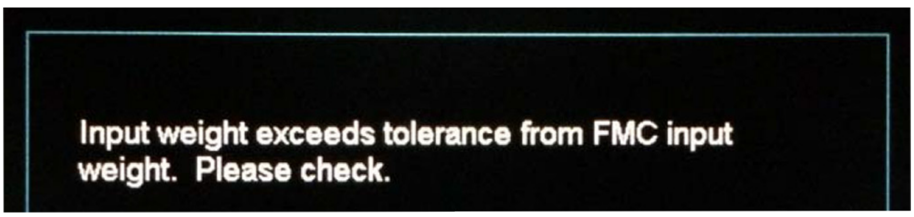
The LINTOP system, developed by Lufthansa Systems, is an on-the-ground remote performance calculation system, which can replace the OPT. It sends the data entered by the crew in the ACARS page (weight, t°, runway, etc.) to a ground system which then carries out the performance calculations and sends the results back to the crew. The latter then manually enter the data in the FMS. LINTOP can compare the weight entered in the ACARS page by the crew with the weight used during the flight preparation[(51)]. If the deviation is too high, and if the weight entered is lower, the crew is warned (in % of difference).

[(51)]Estimated Take Off Weight (ETOW).

LINTOP is available for Airbus, Boeing, Embraer, Bombardier and other aeroplanes.

1.18.8 EFB weight comparison feature on Boeing 777

This EFB weight comparison feature was introduced in 2011. In the EFB, a COPY FMC DATA button is used to copy certain FMS data into the EFB. The EFB compares the TOW entered and the GR WT entered in the FMS. A message is generated by the EFB if the difference exceeds a predefined threshold:



Boeing said that it is an option that needs to be activated. Air France confirmed that the Boeing 777 registered F-GUOC was not equipped with this feature.

Another operator that has activated this option has nevertheless raised the following points:

- another message very similar in appearance may be frequently displayed depending on the order in which the data is entered;
- it is of lesser importance and serves to warn that the comparison is not possible, for example when the ZFW has not been entered in the FMC;
- the frequent appearance of this message, routinely erased by the crews, could erode the safety barrier provided by the message which is intended to alert the crew of too great a difference between the weights entered in the EFB and the FMC.

1.18.9 Airbus TOS and TOM systems

The Take-Off Securing (TOS) system detects inconsistencies in the parameters entered in the FMS based on:

- check for ZFW consistency, warning if inconsistency between the speeds entered and the TOW;
- detection if take-off speeds not entered;
- check to detect inappropriate setting (trim, high lift configuration);
- check of aircraft position;
- check of take-off distance.

The Take-Off Monitoring (TOM) system monitors the acceleration of the aircraft during take-off by comparison with the performance data entered in the FMS. The system makes it possible to detect an erroneous TOW, degraded aircraft performance parameters (low thrust, residual braking and aerodynamic degradation) or abnormal contamination on the runway. The Airbus TOM system corresponds to the systems discussed in the EUROCAE TOPMS group.

Master Caution / Warning type alerts are provided for each of the checks performed by the TOS / TOM systems.

The various TOS system features are available in the A350 programme.

The TOM system was certified on A380 in February 2018 and should also be implemented in the short term on A350.

The retrofit of TOS and TOM systems for all the other programmes is planned by Airbus. However, the availability will depend on the retrofit possibilities.

1.19 Useful or effective investigation techniques

Not applicable.

2 ANALYSIS

2.1 Scenario

The numbers in brackets shown as (①) refer to the summary diagram at the end of the scenario (Figure 4).

Flight preparation

The crew of the cargo flight, consisting of the Captain and three Co-pilots, met in the flight preparation office. The flight preparation took place without any noteworthy event. The crew was aware that the take-off weight would be close to the maximum weight (347.4 tonnes) due to the scheduled payload and fuel.

Calculations of take-off parameters

The two Relief Pilots carried out the exterior walkaround and checked that the load was safely in place. The Captain (PM) and the Co-pilot (PF) carried out the flight preparation in the cockpit. Due to the thunderstorms expected on arrival, the crew had decided on a fuel load of 2.5 tonnes more than that specified on the Operational Flight Plan (OFP).

The final take-off weight would thus be greater than that foreseen in the preliminary flight preparation phase (indicated on the OFP). In this case, the Air France procedures specify that the data used for the performance calculation is updated in the OPT and that a second cross-check is performed. Both pilots anticipated the new take-off weights taking into account the additional fuel so as not to have to redo the calculations in a limited time after receiving the final data.

To estimate the new data, the Co-pilot calculated the take-off weight in his head by adding the ZFW and the scheduled fuel load. He made a calculation error of 100 tonnes and entered 243 tonnes into his OPT (①). Meanwhile, the Captain also calculated the take-off weight in his head by correcting the take-off weight provided by the flight plan with the difference between the scheduled fuel load and the selected fuel load. He obtained 343 tonnes. But he entered 243 tonnes in his OPT (①).

In the absence of any recording, it was not possible to determine if the two errors were independent or if one of the crew members was influenced by the verbalization of an erroneous value by the other crew member. The cross-check of the equality of the OPT calculation results did not permit the error of 100 tonnes to be detected (②).

Entering data in FMS

In accordance with the airline's CDU PreFlight Procedure, the crew began to enter data in the FMS.

The Co-pilot (PF) entered the planned ZFW in the FMS (③). He entered the balance and flap setting in advance. The flap setting from the performance calculation was 5° whereas it would have been 15° with the actual weight of 343 tonnes. This configuration value did not alert the crew. Since the introduction of performance optimization at Air France, the 5° flap configuration is statistically predominant for take-offs on Boeing 777-F (cargo) and is used for about half of the entire 777 fleet.

When the crew entered the speeds from the OPT, they noted that the FMS displayed significantly higher reference speeds (Figure 1). The crew thought that this difference might result from an instability of the probe measurement due to the refuelling then in progress. The Captain and the Co-pilot then performed other tasks.

The reference speeds V1, VR and V2 were calculated by the FMS and displayed on the TAKE OFF REF page. The calculation was based, in particular, on the ZFW weight entered by the crew.

Figure 1: Example from simulation
Reference speeds versus entered speeds

TAKE OFF SPEEDS DELETED and V SPEEDS UNAVAILABLE messages

In the conditions of the day, and as soon as the TOW is greater than 330 tonnes with a flap setting of 5°, the FMS can no longer calculate the reference speeds and a V SPEEDS UNAVAILABLE message appears.

During refuelling, while the crew was performing other tasks, the TOW reached 330 tonnes and the TAKE OFF SPEEDS DELETED message appeared on the FMS screen page that was currently displayed (not necessarily the TAKOFF REF page). The crew probably deleted this message along with the following V SPEEDS UNAVAILABLE message, without paying any particular attention.

Reception of final data

The two Relief Pilots came back before the Final Loadsheet arrived.

The Co-pilot (PF) performed the take-off briefing and said in particular, "*We are heavy*".

When the Final Loadsheet arrived, the Captain compared the FMS data with that of the Final Loadsheet (④). They were globally consistent. He called out the load to the Co-pilot (⑤). The latter recalculated the data manually (Figure 2). He made the mistake of 100 tonnes a second time and obtained the same erroneous result as that entered in his OPT. After comparison, he told the Captain "*it is compliant*" ⑥);

The manual calculation is as follows:

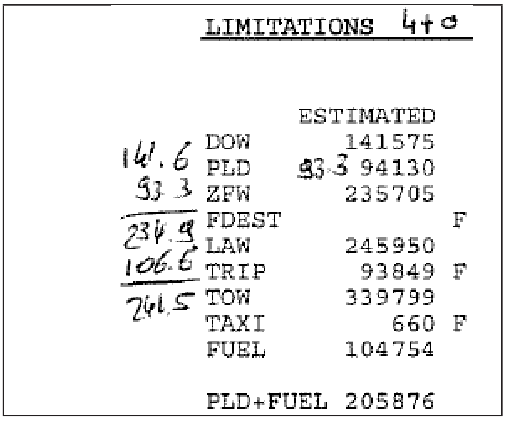
Dry Operating Weight (DOW) (141.6)

\+ PLD (93.3)

= ZFW (234.9)

\+ definitive fuel load (106.6)

= 241.5t


LIMITATIONS 410

		ESTIMATED	
141.6	DOW	141575	
93.3	PLD	93.3 94130	
234.9	ZFW	235705	
106.6	FDEST		F
241.5	LAW	245950	
	TRIP	93849	F
	TOW	339799	
	TAXI	660	F
	FUEL	104754	

PLD+FUEL 205876

Figure 2: Excerpt from the Co-pilot's Operational Flight Plan (OFP)

Final entries

When refuelling was complete, both crew members re-entered all of the data in the FMS, starting with the ZFW. The V SPEEDS UNAVAILABLE message was displayed when all the data necessary for calculating the speeds had been entered. When they displayed the TAKEOFF REF page, the reference speeds no longer appeared. They tried to display them, without success, by repeatedly pressing the ON/OFF key corresponding to the REF SPDS function of the FMS (Figure 3).

The 5° flap configuration, the assumed temperature of 37° and the take-off speeds from the Captain's OPT were then entered. The values were as follows: V1 143 kt, VR 152 kt and V2 156 kt (instead of 167 kt, 175 kt and 179 kt for a flap configuration of 15° and an assumed temperature of 58° calculated by the OPT with a correct weight).

V SPEEDS UNAVAILABLE message

Speeds entered without reference speeds

Figure 3: Screenshots of FMS
Take-off parameters close to those of the incident

The crew did not question the consistency of the speeds entered, since the FMS had not prevented the entry. After pushback and when the Captain requested flaps 5°, a Relief Pilot was surprised because he expected the flap 15° configuration. He did not, however, express his misgivings and convinced himself that this performance calculation result was possible with this specific version of Boeing 777 (777-F cargo).

Take-off

The aircraft lined up on runway 26R and took off at 10:25.

The rotation started when the Calibrated Air Speed (CAS) reached 154 kt. Just after the rotation, the PF and the three other crew members immediately felt that the aircraft was sinking. Five seconds after rotation was initiated, the tailstrike protection was fully activated. Without this protection, the aeroplane tail would have probably struck the ground one second later. The main landing gear wheels were still in contact with the ground and the pitch stabilized at 9°, below the tailstrike pitch angle. There was no tailstrike during the event. From the beginning of the rotation, the Captain looked outside.

Eight seconds after the activation of the tailstrike protection, full thrust was applied in response to "*TOGA!*" being called out by one of the Relief Pilots. The aeroplane was then at a radio altitude of 16 ft, the pitch was 13°, the CAS 189 kt. The aeroplane clearly accelerated. The Captain was concerned about the height and the vertical speed. He ordered the retraction of the landing gear when the vertical speed was approximately +1500 ft/min. The pitch increased towards 16° and the aircraft flew over the opposite threshold 08L at a radio altitude of 172 ft.

The other Relief Pilot monitored the speed and helped the PF maintain the speed over the MMS[52] and the pitch under that of the PLI[53].

There was no approaching stall warning (Stick Shaker) during the take-off and climb.

Subsequently, the crew discussed several hypotheses as to the causes of the event. The data calculation and entry errors were discovered when the PF consulted his OPT. The PF was relieved at around FL200.

The crew members discussed whether to turn back but decided not to because they felt fit to continue the flight to Mexico City. The FCOM TAIL STRIKE procedure was not mentioned.

Arrival

The arrival and landing took place normally. After the aeroplane was stationary, the crew members carried out an exterior walkaround and confirmed the absence of a tailstrike. They were relieved after the incident by the airline company.

The following diagram summarizes the main checks of the take-off weight data.

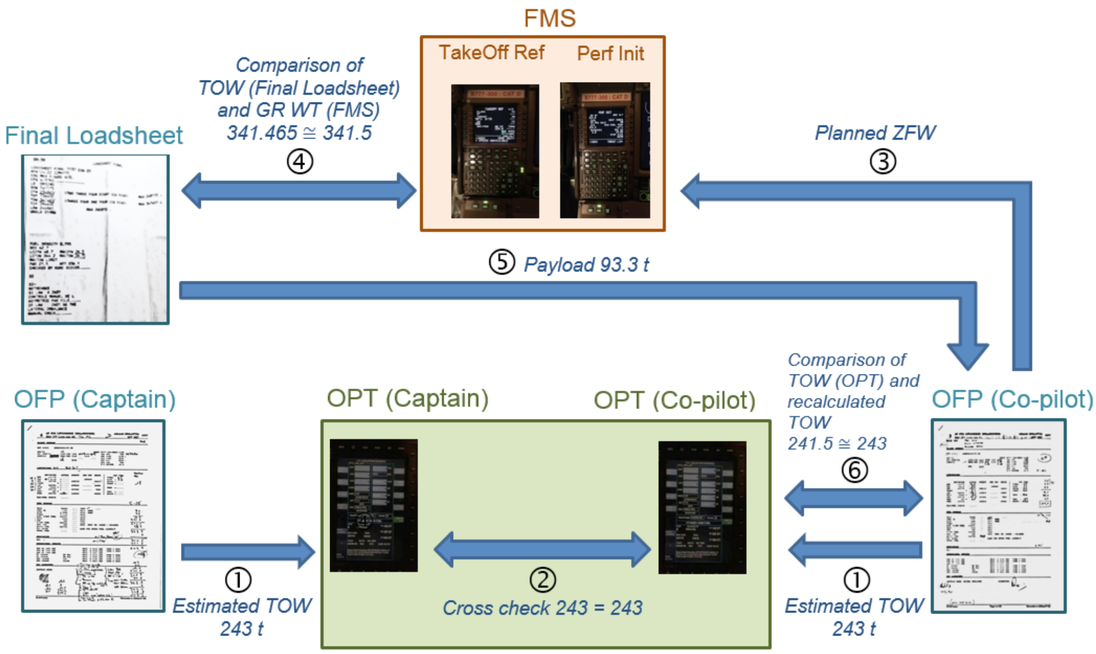


Figure 4: Diagram of the main checks of the take-off weight data during the event

[52] Minimum Maneuvering Speed.

[53] Pitch Limit Indicator.

2.2 Analysis of the event

2.2.1 Performance of operational barriers in the event

The elements from the ASR written by the crew and the pilots' statements indicate that the Captain and Co-pilot did the calculation separately on their OPT, as specified by the Air France procedures. They each entered a weight 100 tonnes below the real weight. They compared the data taken into account and the results once the calculation had been carried out. As the erroneous value was the same for both of them, the results were identical. This first check was therefore ineffective in identifying the error of 100 tonnes. The value of 243 tonnes announced by the Captain did not alert them.

The data available does not make it possible to infer whether or not the two inputs were actually independent. A verbal exchange between the members of the crew could have been the source of this concomitance. This had already occurred on the same type of aeroplane in two similar events in 2009 and 2013. The report produced by the DSB on the 2013 incident states: "*Both in this incident [2013] and the incident in 2009, a pilot mentioned an incorrect take-off weight and the other pilot used that weight, which resulted in the calculation no longer being independent, causing the failure of an important safety net*".

On receiving the Final Loadsheet, the FCOM specifies that the Captain and Co-pilot check it. One of the possible ways of complying with this is the technique applied by the Captain and Co-pilot, i.e. giving the load to the Co-pilot so that he can check the TOW and compare it with that taken into account in the parameter calculation. The manual calculation of the TOW performed by the Co-pilot on receiving the Final Loadsheet gave the same erroneous result of 100 tonnes. This may be explained by the pilot's expectations with respect to the result to be obtained (a weight of around 243 tonnes) interfering in the calculation process. The validation of the Final Loadsheet could constitute a possibility of detecting the weight error. However, the two checks made by the crew at this moment were also ineffective. The calculated weight had the same error as that entered in the OPT and the weight on the Final Loadsheet was the same as that entered in the FMS. The Air France procedures do not include a simultaneous check of the weights on the three formats (FMS, OPT and Final Loadsheet).

The speeds calculated by the FMS constituted an independent source of information which could have given rise to the validity of the calculations being questioned. Neither the considerable difference (20 kt) between the reference speeds and the speeds calculated by the OPT nor, next, the absence of reference speeds the last time the data was entered led the crew to question the calculations carried out in the OPT. This recovery barrier was thus also ineffective the day of the event.

The various procedural barriers as applied by the crew did not prevent the erroneous data entries on the day of the event:

- the comparison of independent calculations;
- the validation of the Final Loadsheet and the check for its conformity with the entered data;
- the use of reference speeds proposed by the FMS.

Although the crew had knowledge of orders of magnitude, this knowledge was not sufficient enough to make them detect the error of 100 tonnes.

2.2.2 Mobilization of orders of magnitude

The scenario highlights an absence of response from the crew to weight and speed values inconsistent with the conditions of the day (a weight close to the maximum weight). The Captain cannot understand how he could have failed to detect the inconsistency between the V2 and the weight. He said he knew the orders of magnitude. The Co-pilot considered that they were aware of having a high weight close to the limits and stated that he was aware of the orders of magnitude of speed as a function of the weight. Thus according to their statements, the pilots knew the orders of magnitude but did not mobilize them in their working memory during the flight preparation.

Three main factors may explain why these orders of magnitude were not used:

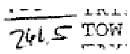
- the diversity of the formats and media;
- the multiplicity of simple checks;
- trust in the systems.

Diversity of formats and media

The study published by the BEA in 2008, and in particular the analysis of incident reports, underlined the multiplicity of weight values handled and the relative ineffectiveness of the associated procedural steps for checking these values.

The following table shows, by way of illustration, the various formats and denominations handled by the crew during the event flight just for the take-off weight.

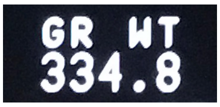
Weight entered in the OPT



Weight calculated on the OFP

Weight which may be printed on the Take-off Card

Weight shown on the Final Loadsheet



Weights displayed on the FMS

Weight shown on the OFP

Figure 5: Various representations of the TOW used during the event

The study concluded that the various notions handled (GR WT, TOW, MTOW, ZFW, payload, fuel loaded, FOB, etc.), the associated units (kg, 1000 kg, t, l, etc.) and the denominations used (TOW, Take-off Weight, GR WT, Planned weight, etc.) resulted in too many representations for them to be stored in working memory.

The values handled then lose their meaning preventing any comparison with values already handled in an equivalent context, which could, depending on the level of experience of the pilots, have been stored in long-term memory.

Multiplicity of cross-checks

Numerous checks of the take-off parameters were provided for in the procedures (equality of calculation results between the OPTs, equality of calculated speeds and speeds entered, consistency between the weight indicated on the Final Loadsheet and the GR WT displayed on the FMS, etc.). However, the way in which these checks were applied in the cockpit did not prevent the event.

The simple check for the equality of the calculation results did not lead the crew to question the pertinence of the values.

Basic checks are useful for quickly detecting entry errors. These are item-by-item comparisons that do not result in questioning the relevance of the values. "*A false item = a false item*" is a correct but insufficient check. In fact there was no global consistency check, and no gross error check.

Trust in the systems

Speed values can be difficult to estimate:

- ❒ crews fly on different types of Boeing 777;
- ❒ since optimizing take-off performance, the flap configuration often changes and crews have different speed ranges to enter.

In the event, one Relief Pilot was surprised by the F-GUOC configuration value but he did not question it, trusting the OPT calculations.

Furthermore, on entering the speed data for the first time and seeing the inconsistency of the speeds between the FMS and the OPT, the crew thought that the values proposed by the FMS were false because refuelling was in progress. This explanation was erroneous because with the increasing weight, the reference speeds could only increase as well. At that moment, the crew took the first plausible explanation and differed their action without trying to question it again afterwards.

These two misunderstandings of the results without questioning them, highlight the crew's loss of control in the calculation of parameters and the "*blind*" confidence in the calculations made by the systems as a result of this.

The pilots' knowledge of orders of magnitude of parameter values determined by empirical methods is often cited as a safety barrier to prevent significant errors. However, this knowledge decreases with the use of precise calculations for parameter optimization.

2.2.3 Compatibility of procedures and interfaces with operational environment

Workflow

In the event, the pilots did not enter data (TOW from OFP) that they knew was already out of date (due to the fuel that was added) and thus had to carry out the calculations manually. This practice is not unusual, it is the result of routine optimization allowing crews not to perform a new calculation of the parameters after receiving the Final Loadsheet, at a time when their workload increases.

This is in line with one of the observations taken from the 2008 study, namely that the Final Loadsheet constitutes the reference whatever the company and equipment used. The availability of this document is the decisive step which conditions the calculation of take-off parameters and their entry in the FMS. As it is often received late, crews and companies adopt strategies to get around this.

Independence

The event raises the question of the actual independence of a double calculation carried out in the same context with data taken from the same sources. A simple verbalization can make this barrier fallible. This in a context where pilots are accustomed to working as a crew for all tasks and in particular to verbalizing and "*cross-checking*" data entries in the systems, whatever they are. For this reason, it seems surprising, theoretical and tedious to ask pilots to perform calculations separately, side by side.

Furthermore, the procedure requires the input data to be checked and then the results to be checked. If the two pilots share information on the data entered, the comparison of the results makes it possible at best, to validate the operation of the OPTs.

Sequence of procedures

The specified sequence of procedures has some unclear areas.

For example, it is indicated that the EFB Procedure for calculating parameters can be started at any time during the Preliminary Preflight Procedure and after entering the routes. Yet the routes are entered during the CDU Preflight Procedure, which starts after the Preliminary Preflight Procedure.

The Before Start Procedure only starts once the Final Loadsheet is on board. This procedure requires the steps be carried out relating to the performance data (ZFW and CG) of the CDU Preflight procedure. This seems to suggest entering the ZFW in the FMS twice: initially taking the value from the OFP and secondly from the Final Loadsheet but without this being clearly specified in writing.

The procedures have been modified since the event, but Air France's investigation internal report (cf. paragraph 4.1.1) mentions that there is still some doubt about when to calculate the parameters.

This illustrates the difficulty of designing procedures based on a linear sequence of actions in an operational context where tasks are frequently interrupted and where the interfaces are not necessarily compatible with the actual way in which the preparation occurs in everyday operations (for example preliminary data and then definitive data).

2.2.4 Reference speeds calculated by FMS, V SPEEDS UNAVAILABLE message

Using reference speeds

During the first attempt to enter speeds, the very large difference between the FMS reference speeds displayed and the speeds calculated by the OPT clearly alerted the crew. However, this was insufficient for them to identify the source of the problem. The crew stopped at the first hypothesis which seemed plausible (the unstabilized fuel weight probe). When the crew re-entered all the data in the FMS once refuelling was completed, they did not find the reference speeds. The crew attempted various actions to restore the display of these speeds. As the entry of the speeds was not blocked by the FMS, the crew was able to enter speeds even in the absence of reference speeds.

Air France procedures and training did not detail the actions to be carried out in the absence of reference speeds.

According to Boeing:

- some operators use these reference speeds for comparison with the dispatch speeds;
- most operators do not use the reference speeds;
- some operators have aircraft that do not display reference speeds.

This raises the question of the use of reference speeds by the crews. If some airlines use them as a means of detecting gross errors, one may legitimately wonder why this is not widespread. Clearly, crews lack the elements to use the reference speed values as an effective safety barrier.

Salience of V SPEEDS UNAVAILABLE message

The V SPEEDS UNAVAILABLE message was generated twice:

- A first time during refuelling: from a certain weight, the configuration of the aircraft (flaps 5) was no longer compatible with the speeds calculated by the FMS in the conditions of the day. This resulted in the deletion of the reference speeds and the appearance of the V SPEEDS UNAVAILABLE message.
- A second time, when the crew re-entered all of the data.

The crew probably deleted the V SPEEDS UNAVAILABLE message twice without understanding and/or paying attention to it. This was also the case in the two serious incidents mentioned in the DSB investigation report. The message thus seems to be automatically deleted by crews while the on-going absence of reference speeds raises questions.

The V SPEEDS UNAVAILABLE message, a simple informational message, does not alert the crew about its potential importance. It does not detail the reasons why the speeds cannot be calculated. Nor does it provide information about the consequences (loss of protection, unauthorized take-off in some cases).

Meaning of V SPEEDS UNAVAILABLE message

Air France procedures and training did not detail the actions to be carried out on the V SPEEDS UNAVAILABLE message appearing or on the absence of reference speeds.

The actions to be taken by the crew members when they see this message can be very different:

- In some cases, some of which are not that unusual according to Boeing, but not described in the FCOM, the crew can use the OPT-optimized speeds and continue the take-off.
- In the only case described in the FCOM (high thrust-to-weight ratio), take-off is not authorized because some certified limits are exceeded. The crew must adjust the take-off parameters before taking off.

Boeing does not provide assistance to allow a crew to make the decision to continue take-off if the V SPEEDS UNAVAILABLE message appears. Boeing told the BEA that it was up to the operators to have appropriate procedures.

The analysis of very similar serious incidents in 2009, 2013 (PH-BVG) and 2015 (F-GUOC) highlights the fact that the documentation has remained incomplete and that the operators still do not have full knowledge about the calculation logic of reference speeds and the appearance of the V SPEEDS UNAVAILABLE message. Operators have asked Boeing many questions about this. In particular, Air France recommended that Boeing describe the required actions associated with the V SPEEDS UNAVAILABLE message.

Effectiveness of safety barrier constituted by reference speeds and V SPEEDS UNAVAILABLE message

On 777, it remains possible to enter OPT optimized speeds in the FMS and perform a take-off, even if the FMS is incapable of calculating the reference speeds. The purpose of the V SPEEDS UNAVAILABLE message is not really to warn about the entry of inconsistent data but above all to inform about the calculation limits of the FMS, whatever the reasons. This makes it difficult for the crew to interpret this message, which is more related to a technical limitation of aircraft systems than to information relevant to operational decision-making.

For comparison, on 737, the same V SPEEDS UNAVAILABLE message requires the crew to check the entered data and take-off is not authorized.

It is interesting to note that in this serious incident to F-GUOC, the absence of reference speeds constituted more striking information for the crew than the V SPEEDS UNAVAILABLE message.

Despite the measures taken by an operator after the serious incident in 2009 to improve the procedures, a similar serious incident (PH-BVG) involving the same operator reoccurred in which the crews did not understand the message. Further to the serious incident in 2013, this operator issued a recommendation to Boeing to improve the wording of the V SPEEDS UNAVAILABLE message. The DSB also questioned Boeing about the meaning of this message and asked Boeing if any improvement of the display would be possible. Boeing replied that no change was planned for the V SPEEDS UNAVAILABLE message.

In the light of the F-GUOC serious incident, the questions the DSB raised regarding the presentation of the message and its meaning are still relevant.

As it is, the V SPEEDS UNAVAILABLE message remains a low-level safety barrier.

2.2.5 Protection against entering take-off speeds that are too low

When the FMS cannot calculate reference speeds, (V SPEEDS UNAVAILABLE message), the FMS protection which prevents the entry of speeds below the calculated minimum speeds (V1min, VRmin, V2min) is no longer available, without the crew being warned of this.

In the FCOM, this loss of protection is not clearly described.

In his statement, the Co-pilot (PF) of F-GUOC said that there was no display of V1 min or VR min. He knew the existence of this protection and thought that if the system did not prohibit the speed data from being entered, the situation was normal. Thus, the possibility of entering speeds despite the absence of minimum speeds did not lead him to question the relevance of the values entered.

As a comparison, on 787, the FMS does not calculate reference speeds and the V SPEEDS UNAVAILABLE message does not exist. Take-off speeds are calculated by the OPT. The MIN VSPEEDS UNAVAILABLE message, associated with the help message, "*Unable to compute Take-off speeds for current conditions*" clearly informs the crew when the protection against entering speeds that are too low, is lost. This message cannot be deleted all the while the values entered do not allow the calculation of take-off speeds and take-off is not authorized.

2.2.6 Take-off timing

The timeline of the take-off is as follows:

- T0: rotation initiated, passing VR;
- T0 + 5 s: activation of tailstrike protection, pitch stabilized at 9°;
- T0 + 7 s: pitch and air speed slowly increased;
- T0 + 8 s: transition ground / air of the main landing gear;
- T0 + 13 s: application of TOGA thrust.

The application of TOGA thrust supposes that the crew detects the anomaly and chooses to readjust the thrust.

The detection of a parameter problem at take-off is difficult, there is no alert to help with its detection or analysis. The rotation rate is one of the cues which can be used by the crew principally by using external visual references.

Eight seconds were then necessary for the crew to opt for TOGA thrust and to apply it. This period seems consistent with the element of surprise, that the problem was not understood and that the application of full thrust is not the sole and obvious solution.

2.2.7 Decision to continue flight

Once the incident was over, the flight crew considered the risk of a tailstrike and continuing the flight. The TAIL STRIKE procedure applies when a risk is suspected or proven. It requires them, among other things, to land on the nearest aerodrome. As the Captain was sure that the tail of the aircraft had not touched the runway during take-off, the crew decided to continue the flight.

The decision to continue the flight or to turn back and land at Paris - CDG required the crew to analyse the situation and the risks associated with each solution. This type of analysis may require outside assistance, guiding the crew not only on the decision to be made, but also on the items to be monitored in one or other of the chosen solutions.

The Co-pilot (PF), aware of having been affected by the incident, was relieved after the initial climb. For the event flight, there were sufficient crew members to ensure the flight. Nevertheless, the changing of Co-pilot raises the question of the ability of a crew to continue the flight after the occurrence of an incident. There are no systems to guide crews in these situations and encourage them to seek the help they may be able to use. The assessment of the situation is left to the crews' judgement. They may not have sufficient hindsight to make an objective decision.

2.2.8 Conclusion on event

Previous studies on entry errors had highlighted the difficulties experienced by crews in applying procedures to the letter, that take little account of the operational aspects of the flight preparation phase. The 2008 study published by the BEA also emphasized that the multiplication of checks was not a guarantee of robustness. In particular, it highlighted the lack of an overall consistency check, i.e. simultaneous comparison of the weight data used in the Final Loadsheet, OPT (EFB) and FMS as well as the absence of a systematic means of detecting gross errors (use of orders of magnitude or use of reference speeds).

These conclusions remain valid with respect to the Air France procedures in force on the date of the event for the calculation and entry of the parameters. The airline's procedures, whether those described in the FCOM or those described in the training manual, were not robust with respect to the comparison of take-off weights.

Ergonomic problems with the FMS had also been pointed out. It appears that the FMS still allows speed values inconsistent with the entered weight, to be entered. In addition, this is the third known serious incident on Boeing 777 where the V SPEEDS UNAVAILABLE message did not alert the crew or was not understood.

The intervention of a third member of the crew resulted in effective action: the application of full thrust.

The crew did not turn back to Paris. The decision to continue the flight is left solely to the crew's judgement, who may not have after an event of this order, the hindsight necessary to assess the situation and their own ability to continue the flight.

In conclusion, the failures analysed in the serious incident involving F-GUOC had already been identified in the three international studies quoted in this report. It is therefore fitting to consider the reasons why this type of event continues to occur with the same causes and contributing factors.

2.3 Risk management by Air France

The risk of an entry error has been the subject of several initiatives by Air France, either continuously or following a significant incident in 2004 on one of the airline's A340s. These initiatives took the form of ad hoc analyses, notably on the basis of incident reports collected via ASRs, the inclusion of the topic in the training program, the modification of certain operational media, requests for modifications addressed to manufacturers, or internal publications.

When OPTs were introduced from 2009 on the airline's 777-F (cargo), operators were not required to conduct safety studies prior to the changes. Air France had launched an internal working group and participated in the study commissioned by the BEA. Nevertheless, the working group did not continue its analyses and the procedures were not modified accordingly.

The procedures put in place have the same weaknesses as those highlighted by the 2008 study published by the BEA: a very partial recognition of operational constraints, handling of weight data in different formats, a multiplication of checks, no check for overall consistency of the values used, in particular no simultaneous check of the weight values used in the Final Loadsheet, OPT (EFB) and FMS. This highlights weaknesses that may exist in the design of suitable procedures and in their validation in a real context (when they are being set up and during operation).

Air France relied on several types of flight observations. Flight audits have limited effectiveness in this area due to the focus on compliance. In addition, the auditor pilots are not necessarily always qualified on the aeroplane type. This principle is intended to ensure the independence of the inspection but may partially compromise the ability to detect the possible fragility of certain procedures.

The checks carried out by the TREs are not intended to assess the robustness of the reference frames but essentially the crews' performance within these reference frames.

Furthermore, before the F-GUOC serious incident, Air France had begun exploring two ways of detecting such events through its flight analysis system. While an incident such as that concerning F-GUOC was actually detectable, the system was still not considered effective enough to detect the various data entry errors that can be made. In this initiative, Air France did not receive the expected assistance from manufacturers.

For various reasons, internal and external to Air France, these initiatives did not allow the airline to put in place sufficiently robust procedures with respect to the errors that contributed to the F-GUOC serious incident.

EASA in its analysis underlines the universal nature of data entry errors. The recurrence of these incidents and accidents, which involve different operators around the world, shows that, in fact, Air France is not the only company to experience difficulties with respect to this safety issue. Too many organizational and operational contingencies can compromise the thinking processes started or the measures implemented by operators. This is in line with the findings of numerous studies and investigations published in the past, confirming that operators cannot manage this risk alone.

In 2014, EASA published AMC 20-25 on the use of EFBs. The means of compliance contained therein incorporate certain lessons learned from the analysis of past incidents and accidents. Although they are probably still not sufficient with respect to all possible operational contingencies, some of these recommendations are relevant with respect to the weaknesses highlighted by the F-GUOC serious incident. During the period between the publication of AMC 20-25 in February 2014 and the F-GUOC serious incident in May 2015, Air France did not conduct any changes on the EFBs of its Boeing 777 fleet which required it to use this document. Since then, the SIB published by EASA[54] refers to it and should encourage operators to check that the principles developed therein are correctly taken into consideration, even if they have not foreseen any particular changes in the use of their EFB. AMC 20-25 can now be a reference document for operators.

[54] SIB 2016-02. Cf. paragraph 4.1.3.

2.4 Risk management by DSAC

In September 2008, in response to recommendation FRAN-2008-022 sent by the BEA as part of its study, the DGAC determined specific points to be checked in order to ensure the robustness of operator procedures. In particular:

- the parameters must be prepared independently;
- the order of magnitude must be cross-checked by the other pilot;
- time must be left to crews to do these checks.

The DGAC also mentioned that manuals had to be modified if the above provisions were not in place and that the voluntary feedback from crews on incidents should be encouraged.

Between 2008 and 2015, both Air France's operating procedures and DSAC's oversight methods evolved. The transition to the manufacturer's documentation was an opportunity for the DSAC to study certain elements of the Air France operations manual. In addition, as part of the monitoring of SMS that it had put in place, the DSAC had the opportunity to draw the attention of operators to good practices, especially with regard to the risk of incorrect weight and balance. The consideration of these good practices has been verified on various occasions.

In particular, with regard to the operational implementation of these procedures, flight inspections were carried out by the DSAC, which included a dedicated item. However, in the absence of errors that actually occurred and were observed during these inspections, it was difficult for the DSAC to question, on the basis of these inspections only, the robustness of Air France's procedures.

Overall, DSAC's oversight did not lead them to ask Air France to change its procedures, despite weaknesses already identified in the 2008 safety study published by the BEA. Before the F-GUOC serious incident in 2015, the DSAC considered that Air France's procedures for calculating and entering take-off parameters were satisfactory.

2.5 Risk management by civil aviation authorities

Since 2005, following several safety investigations and safety studies focusing on the use of erroneous parameters at take-off, several safety recommendations have been addressed to various civil aviation authorities worldwide. Most of these safety recommendations focus on the need to implement new on-board systems to prevent the use of erroneous parameters or to warn the flight crew of anomalies.

Depending on the system in question, civil aviation authorities had sometimes mentioned limitations with regard to the recommended systems or had defined a limited scope for their implementation. For instance:

- From 2006 to 2017, Transports Canada had indicated that there were no TOPMS that were suitable for the envisaged use in civil aviation and that the industry was best placed to take the lead in developing them. The research project established by Transports Canada in 2007 had come to a standstill in 2009 due to the lack of appropriate funding.
- In 2009 and then in 2011, the FAA explained that recommendations from the task force it had mandated to study methods of error checking would apply only to new airworthiness approvals. The FAA has in fact refused to require the retrofit of existing FMS considering that operators already have policies restricting certain erroneous entries.

Between 2005 and 2012, eight safety recommendations prompted EASA to take action on the risk of entry errors. Broadly, these recommendations focused on:

- TOPMS (three recommendations from 2006 onwards);
- OBWBS (two recommendations from 2005 onwards);
- EFBs (two recommendations from 2011 onwards);
- Systems for detecting entry errors similar to the TOS features developed by Airbus (one recommendation in 2008).

With regard to TOPMS type systems, EASA limited its work to that of WG-94, which began six years after receipt of the first safety recommendation on the subject. Having found that the members of this group had not reached agreement on the possibility of standardization, EASA did not further seek to promote the development or deployment of these systems, even non-standardized. Thus, with its own resources, EASA did not try to draw up specifications or have prototypes developed. Despite this and in parallel, Airbus developed and started to deploy the TOM feature on A380, thus demonstrating the technical feasibility and advantages of this type of system. While the possibility of studying the appropriateness of a standardization has again been mentioned by EASA, no precise date has been put forward.

WG-88, for its part, began its work in 2010 under EASA's impulsion, five years after the first recommendation on OBWBS type systems. While recalling the operational impacts that compromised some previous projects, the group concluded in 2013 that the standardization of OBWBS was feasible and desirable. Although on this basis EASA announced the start of the drafting of specifications (MOPS) in June 2013, a new call for participation was only issued by EUROCAE at the end of 2015, i.e. a few months after the F-GUOC serious incident. WG-88 started new work in 2016, this work being presented by EASA as a prerequisite for any regulatory action (RMT.0116) on its part. At the same time, EASA left the chairmanship of the group to the industry, thus accepting that it would have less control over actions and timelines.

Before considering making a new technical system mandatory, EASA draws on the expertise of the industry to assess its feasibility and define specific features. The process currently in use may, however, lead to the analysis being almost exclusively the responsibility of a few industry representatives, in particular within the framework of EUROCAE. While this ensures that EASA does not work in isolation and that a realistic approach proportionate to the technical maturity of the industry will be taken, EASA no longer controls the deadlines or the terms of the question asked.

EASA's analyses following the recommendations on EFBs led to the publication of AMC 20-25 in 2014. The document contains a set of provisions to be implemented by operators when deploying a new EFB system or when making certain modifications to them. Several of these provisions appear relevant in view of the weaknesses highlighted by the F-GUOC serious incident. This is the case in particular for:

- the definition of a program of evaluation tests;
- the search for a high level of consistency between the EFB and other equipment or information media;
- the notion of gross-error check.

The processes initiated on the OBWBS, TOPMS and EFBs have guided EASA's thinking since 2010. At that time, in its responses to the BEA's 2008 recommendation on systems for the detection of gross errors when entering parameters, EASA mainly refocused the discussion around these three systems and related work.

Nevertheless, in the same responses, EASA indicated that it should study the effectiveness of systems for the detection of gross errors on entering data. For example:

- The TOS system developed by Airbus includes various features (checking the consistency of weights and speeds entered for example). These features were mentioned during the WG-94 work although they did not fit entirely within its remit. Furthermore, the arguments put forward against the standardization of TOPMS type systems were globally not applicable to TOS features.
- For its part, Boeing developed its own features (for example: verification $V1 \leq VR \leq V2$ performed by the FMS or a comparison made by the EFB between the weight calculated by the FMS and the weight entered in the EFB), with different operating logics between those applied on Boeing 777 and those retained more recently for Boeing 787.
- In addition, LINTOP is an example of a third party system chosen by some operators to check the Gross Weight entered in the FMS.

In the end, EASA did not analyse these detection systems, spontaneously developed by certain aircraft and equipment manufacturers, as it had undertaken to do in its responses to the BEA. This is all the more regrettable in that, for example, the EFB feature which compares the weight could theoretically have prevented the three similar serious incidents (the F-GUOC in 2015, the PH-BVG in 2013 and the incident in 2009 involving the same operator).

Even in the light of certain demonstrations (Airbus simulation of the operation of the TOS in the circumstances of an investigated accident), EASA only questioned the genuine benefit of such systems.

The three similar serious incidents showed that the Boeing 777 information message was insufficiently salient. They confirmed that at least, it would have been and still is useful to list, study and possibly standardize the operating modes of existing systems enabling the detection of gross errors among the parameters used at take-off.

Overall, the work conducted by EASA as well as by several other civil aviation authorities, particularly in their handling of the safety recommendations addressed to them, meant that F-GUOC was not equipped with systems or features to prevent the use of erroneous parameters or warn the crew about the resulting anomalies. The industry has progressively developed more effective systems, but authorities either seemed to ignore these developments or did not consider how their use could be promoted or extended.

3 – CONCLUSIONS

3.1 Investigation findings

- The crew held the necessary licences and ratings to carry out the flight.
- The aeroplane had a valid Certificate of Airworthiness and was maintained in accordance with regulations.
- The composition of the crew was in accordance with the operator's procedures.
- The take-off weight taken into account in each OPT for the calculation of the parameters was erroneous by 100 tonnes.
- The take-off weight computed by the FMS based on the Zero Fuel Weight (ZFW) was correct.
- The crew inserted, in the FMS, take-off parameters (flap configuration, thrust, speeds, etc.) corresponding to a take-off weight 100 tonnes less than the actual take-off weight.
- The way the cross-checks were applied in the cockpit failed to detect the 100 tonnes error and the resulting erroneous parameters.
- The verification of the Final Loadsheet as performed by the crew did not enable them to detect the difference between the weight indicated on the Final Loadsheet and the weight used to calculate the parameters.
- The procedures partially took into account the operational aspects of the flight preparation phase and multiplied the number of elementary checks.
- The procedures did not provide for a simultaneous verification of the take-off weights taken into account on the Final Loadsheet and in the OPT (EFB) and FMS.
- The procedures did not include a systematic means of detecting gross errors (e.g. orders of magnitude or reference speeds).
- The failures identified in the serious incident involving F-GUOC had already been identified in three international studies on the use of erroneous parameters.
- A V SPEEDS UNAVAILABLE message was displayed while the take-off parameters were being entered in the FMS. This message did not enable the crew to detect inconsistencies in the entered data. The weaknesses of this message which does not sufficiently alert the crew due to both the content and form, had already been reported on several occasions in the past to Boeing.
- The FMS allows take-off speed values which are inconsistent with the take-off weight calculated by the FMS, to be entered.
- When the FMS cannot calculate reference speeds (V SPEEDS UNAVAILABLE message), the crew is not warned of the loss of protection against entering speeds which are too low, below V1 MIN, VR MIN and V2 MIN normally calculated by the FMS.
- The aircraft took off from runway 26R at a rotation speed of 152 kt with a flap 5° configuration. The appropriate corresponding parameters for the actual weight were 175 kt and a flap 15° configuration.
- The tailstrike protection was activated at its maximum level during the rotation and pitch stabilized at about 9°.
- TOGA thrust was applied by the crew eight seconds after activation of the tailstrike protection.
- The aeroplane flew over the opposite threshold at a height of approximately 170 ft.
- The crew realized the entry error during the climb and the PF was relieved.
- The crew continued the flight to their destination.

- Shortly after their arrival, all the crew members were relieved and returned to France as passengers.
- Two events similar to the F-GUOC serious incident have occurred on Boeing 777 aeroplanes operated by another airline in 2009 and 2013.
- The two previous serious incidents gave rise to a recommendation from the operator addressed to the manufacturer to improve the V SPEEDS UNAVAILABLE message. This has not been taken into account.
- The oversight authority did not verify the content of the company's procedures when it changed from TU to FCOM or when the latter changed its weight and balance procedure after the serious incident involving F-GUOC. Under the EU-OPS and Air OPS regulations, this approval was not required by the DSAC.
- Between 1999 and 2015, in commercial air transport, at least 31 serious incidents and accidents involving use of erroneous parameters at take-off, including three fatalities, were investigated.
- Three international studies had carried out in-depth analyses of the use of erroneous parameters.
- The international studies and the investigation reports of the investigation authorities have all pointed out the advantage, but above all the limits, of operational safety barriers.
- The international studies and the investigation reports of the investigation authorities have all suggested the development of new technical solutions to reduce entry errors and their consequences.
- Many converging safety recommendations have been issued since 2005; they focus mainly on the subject of the OBWBS, TOPMS and EFB.
- On the date of the serious incident involving F-GUOC, on the subject of entry errors, the EASA's management of the safety issue had resulted in the publication of AMC 20-25 relating to the use of EFBs.
- The TOPMS working group initiated by EASA concluded negatively about the standardization of these systems.
- The benefit for the improvement of safety of the systems for the detection of gross entry errors (such as the Airbus TOS) was not studied by EASA.
- In the absence of standards or standardization projects, systems dedicated to gross error detection have been developed by several manufacturers according to different philosophies depending on the types of aircraft.

3.2 Causes and contributing factors

The flight over the end of the runway at a low height, during take-off, is the result of a take-off being started with erroneous parameters (take-off speeds too low, and insufficient flap deflection and thrust).

The erroneous parameters, entered in the FMS and used for the take-off were the result of a performance calculation based on a weight which was 100 tonnes below the actual weight of the aeroplane.

The error of 100 tonnes occurred when each member of the crew estimated the planned weight and entered it in their EFB.

The following elements may have contributed to the 100 tonnes error not being detected and its propagation:

- ❐ The crew's handling of take-off weight data in numerous formats, on various media and with various denominations.
- ❐ The non-mobilisation of orders of magnitude partly related to the increasing use of performance optimization tools.
- ❐ Insufficiently robust procedures including numerous basic checks, incompletely taking into account the operational context and how the crew works. These procedures are notably based on a double calculation supposed to be independent, whereas a simple verbalization may undermine this independence. These procedures do not include a means of detecting gross errors or a simultaneous check of the three media using weight data (Final Loadsheet, OPT and FMS).
- ❐ The absence on this aeroplane, as on the majority of commercial air transport aeroplanes, of systems to detect or prevent such gross errors and to warn the crew of them, or of systems to warn the crew that the performances measured during the take-off run are insufficient.

Some of these points were identified a few years ago by various investigation authorities, notably the BEA through a safety study devoted to this problem, published in 2008.

The lessons from the analysis of numerous incidents and accidents throughout the world did not lead the aviation community to significantly progress on this subject up to the serious incident involving F-GUOC.

In particular:

- ❐ Even when the technological state of the art was favourable, the civil aviation authorities did not manage to incite manufacturers to develop and then deploy in a satisfactory way, suitable technical solutions.
- ❐ Likewise, the development, even the deployment of new systems by certain manufacturers, did not lead these authorities, notably EASA in Europe, to study the gains provided by these systems and, if applicable, promote their wider deployment.

4 - ACTIONS TAKEN AND SAFETY RECOMMENDATIONS

4.1 Actions taken since the serious incident

4.1.1 Actions taken by Air France

Subsequent to the serious incident, Air France launched an internal investigation.

In the first instance, Air France took the following precautionary measure[55] for the Boeing 777 sector:

ENTERING TAKE-OFF PARAMETERS

Following a 100 tonne error and pending the conclusions of the investigation in progress, please comply with the following precautionary measure:

In order to prevent the use of erroneous parameters at take-off, crews are asked to check, under the responsibility of the Captain, the consistency between the following three TOW values:

- TOW read on the ECD (and possibly corrected on the LMC)[56],

- TOW calculated by the FMS based on the FOB and the ZFW value entered by the crew,

- TOW entered in the EFB by the crew to calculate performances.

It is imperative that this check is carried out before start-up.

Moreover, the Training Manual (LEF) was updated so that the Captain must share the Final Loadsheet data with the Co-pilot.

Air France also changed the FCOM procedure for calculating performance parameters and entering the data. Appendix 2 presents an excerpt from the new Before Start Procedure.

In particular:

- the roles and actions of the pilots have been clarified;
- it draws the attention of crews to the V SPEEDS UNAVAILABLE message or the possible lack of reference speeds.

The simultaneous check of the take-off weight of the three media, as described in the precautionary measure, have not been clearly transferred to the FCOM procedure.

Moreover, Air France notes in its internal investigation report that a doubt remains as to when the performance parameters should be calculated.

Several recommendations have been made by Air France.

The main recommendations addressed by Air France **to Boeing** relate to:

- improvement in the presentation of the V SPEEDS UNAVAILABLE error message on the CDU;
- improvement of the information in the FCOM about this message.

[55] This measure was originally released in French by Air France.

[56] Last Minute Change.

It was planned to address a recommendation **to EASA** relating to:

- the development of specifications for an on-board system that would allow crews to detect inadequate performance at the start of the take-off run.

However, according to Air France, this recommendation was never sent to EASA.

The main recommendations addressed internally **to Air France** relate to:

- reinforcement of pilot training and the role of the Relief Pilot;
- improvement in the presentation of the flight file;
- the implementation of meeting points during aeroplane preparation to improve communication and situational awareness within the crew, including the Relief Pilot(s).

4.1.2 Actions taken by the DGAC

Following the F-GUOC serious incident, the use of erroneous parameters at take-off issue was added to the agenda of the safety review of the State Safety Program (SSP) piloted by the DGAC.

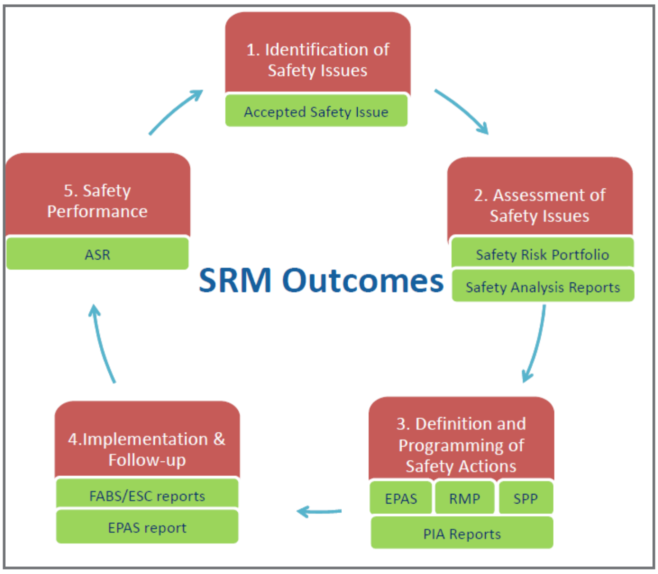
Within this scope, the DGAC conducted a retrospective analysis of the procedures of the operators having previously obtained approval for the use of an EFB. According to the DGAC, The results show the presence of "*cross check*" and "*gross-error check*" procedures for all these operators as suggested by AMC 20-25.

4.1.3 Actions taken by EASA

EASA now includes some of its tasks in a safety risk management process in compliance with the requirements of ICAO Annex 19 regarding Safety Management. The objectives of the EASA safety risk management are to:

- identify safety issues at European level;
- prioritize the safety actions which are the most effective in reducing risk levels;
- ensure adequate internal and external coordination of the identification and assessment of safety issues, as well as the programming of safety actions.

This Safety Risk Management (SRM) process is composed of various steps listed in the following diagram.



Excerpt from a presentation made by EASA at the 2016 EASA-CASIAs meeting[57]

[57] https://www.easa.europa.eu/newsroom-and-events/events/annual-easa-casias-meeting

For the last few years, EASA as a whole has been reorganised and restructured to feed and to benefit from the SRM process. Within the Strategy & Safety Management Directorate, the Safety Intelligence & Performance Department has in fact a transverse role with regard to the Certification Directorate and the Flight Standards Directorate.

The use of erroneous parameters at take-off was one of the first safety issues processed through the SRM process. It was conducted by EASA in parallel with the investigation performed by the BEA. Some of the documents were provided to the BEA during the investigation. EASA issued several specific cautions regarding their reading, in particular:

- the documents provided to the BEA are draft versions;
- the SRM process is an on-going process; findings should not be considered as definitive;
- the whole process is still in its development phase. As an example, data sources for risk monitoring and assessment are not consolidated. Therefore, quantitative results have to be considered carefully.

Safety analysis report

In 2015, following the serious incident to F-GUOC, EASA performed a review and an assessment of the safety issue relating to the use of erroneous parameters at take-off. In this respect, it considered 31 investigation reports and several safety studies issued since 1999. Among the 31 events in commercial air transport that were listed in this review, there were three fatal accidents.

Based on these occurrences, from a quantitative perspective, EASA explained that the data taken into account (including the increase in traffic) tended to show a decrease in the impact of this safety issue over the period studied. However, the agency moderated this conclusion given the small total number of occurrences taken into account. The agency stated that if the evaluation was based solely on this data (including the three fatal accidents, all outside the Member States), the probability of a catastrophic accident occurring would be $6x10^{-9}$.

The risk assessment was also based on a qualitative analysis. Two scenarios were taken into consideration. For each of these two scenarios, EASA identified the negative factors/causes and placed opposite them, the positive factors/risk controls normally available.

As a result of this overall analysis, EASA stated that the risk level associated with this safety issue was "*secure*" (level 6 out of 10), which corresponded to the following definition according to the ARMS methodology[58]: "*the risk level and its trend needs to be monitored continuously […] in order to prevent escalation to unacceptable level. Reinforcement of existing measures should be discussed at the next convenient opportunity […] and taking further reduction measures should be considered*".

The agency noted that the most common key contributing factors to take-off performance data errors were time pressure, crew fatigue, lack of monitoring and situational awareness, availability of the correct initial parameters and failure to comply with standard operating procedures (SOPs).

The fact that serious incidents and accidents continue to occur almost every year means, according to EASA, that the current risk barriers are inadequate and insufficient.

[58] Aviation Risk Management Solutions.

Finally, in its document, EASA drew up a list of new actions to explore in a Preliminary Impact Assessment (see next section). The largest number of new actions (five actions) concerned the management of operations by the operators. Regarding aircraft systems, the list includes the continuation or resumption of work on OBWBS and TOPMS type systems.

Preliminary Impact Assessment (PIA)

The PIA is a new activity which takes place after the safety analysis. It consists of evaluating and comparing the added value of the actions envisaged by EASA with respect to cost-effectiveness and implementation time criteria. These actions might also be complementary to each other over time.

The PIA carried out in 2016 regarding the use of erroneous parameters at take-off was the first one ever conducted by EASA. It was in line with the safety analysis updated in 2015. The version provided to the BEA in 2018 was still in draft form.

Three actions were listed:

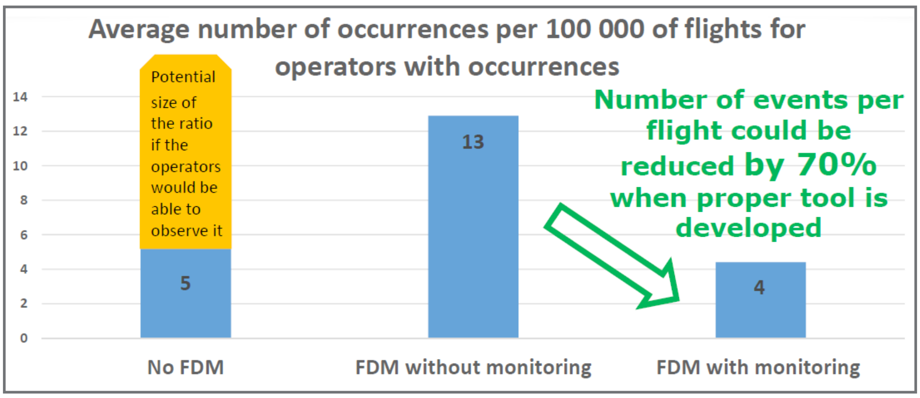
- **Action 1**: publication of a Safety Information Bulletin (SIB) on the Use of erroneous parameters at take-off;
- **Action 2**: OBWBS EUROCAE WG-88 – On-Board Weight and Balance System;
- **Action 3**: RMT.0601 Improve the use of EFB with the updated provisions of AMC20-25.

To assess the safety benefit of the publication of the SIB (Action 1), a survey was conducted by EASA between October and December 2015. Eighty-six operators answered this survey, reporting 128 occurrences over the 2010-2014 period. These operators were divided into 3 categories:

- category 1 operator: those without FDM;
- category 2 operator: those using FDM, without setting up detection criteria regarding the use of erroneous parameters at take-off;
- category 3 operator: those using FDM with criteria adapted to this issue.

Taking into account the exposure data, the average number of occurrences calculated per 100,000 flights is:

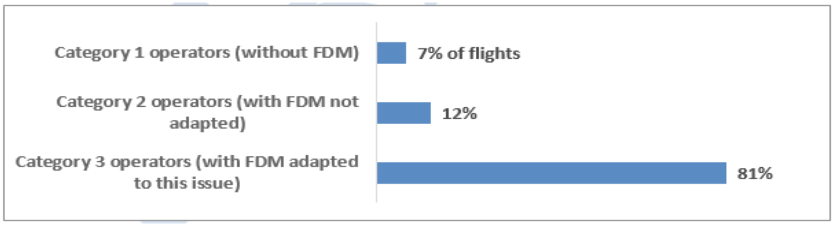
- 13 for operators in category 2;
- 4 for operators in category 3.



Excerpt from a presentation on the PIA carried out by EASA

On the basis of this comparison, EASA concluded that an operator could reduce the number of incidents of this nature by at least 70% with an adequate FDM system.

An appendix to the PIA contains the raw results of the survey, including the distribution of operators in each category (1, 2 and 3) and their associated average number of flights[59].



Proportion of the activity (in number of flights) based on raw results of the survey

However, data collected through this first survey was considered insufficiently reliable by EASA to complete the reasoning and thus assess the global safety benefit of the SIB.

Therefore, EASA was not able to make the planned comparison between the expected safety benefits of the measures envisaged (in particular between the SIB and the OBWBS). EASA intends to organize a new survey.

The BEA notes that, based on this first survey, only 19% of flights are carried out by operators who do not have an FDM adapted to the issue (categories 1 and 2), which would seem to show that the overall potential benefit to be attributed to the FDM, and possibly the SIB, would be limited.

Cost for the publication of the SIB was assessed at 3 based on a scale from 0 (low) to 10 (very high) and the implementation time is assessed to be two years.

The assessment of the safety benefit that Action 2 (OBWBS) could provide is based on the analysis of the 31 investigation reports. As far as Member States are concerned, 10 of the 19 occurrences could have been avoided according to EASA, if a system of this nature had been put in place. The safety benefit of this action is estimated at "*5*" (50% reduction in the probability of occurrence). EASA could not assess the cost and the time for implementation of OBWBS because these parameters depend on the results of WG-88, still preparing the MOPS at the date of publishing this investigation report.

The 3rd action (Publication of AMC20-25 regarding the use of EFB) was not assessed in the first versions of the PIA.

EASA has temporarily concluded that the publication of a SIB to alert operators and flight crew of operational mitigation measures would be the most effective action. In the event that it does not lead to the expected outcome (following a monitoring assessment), the rulemaking task on the development of Minimum Operational Performance Specifications (MOPS) for the On-Board Weight and Balance System (OBWBS) could be the second preferred option, once EUROCAE WG-88 has confirmed the feasibility of such specifications.

The agency assessed that the proposed actions once implemented would reduce the criticality of the risk from "*secure*" to "*monitor*" ("*monitor throughout the routine database analysis*" according to ARMS methodology).

[59]It indicated that 73% of respondents have FDM and that of these, 51% have set up criteria adapted to the detection of this safety issue. In addition, the operators in category 3 on average carry out 59,196 take-offs per year, compared with 9,445 for operators in category 2 and 6,847 for operators in category 1.

Safety Information Bulletin (SIB)

EASA published the SIB Use of erroneous parameters at take-off on 16 February 2016[60].

The objective of the SIB was to increase the awareness of operators and the competent authorities with respect to the safety issue of using erroneous parameters at take-off and to manage this safety issue. It contains several recommendations for operators concerning:

- conducting a risk analysis and assessment, as well as setting up appropriate measures;
- the need to reinforce crew training, to prevent the risk of errors, to detect anomalies during take-off and to react effectively when necessary;
- the setting up of a suitable monitoring mechanism through the FDM (reference is made to the European working groups on FDM coordinated by EASA).

Although the recommendations were addressed to operators, EASA recalled that among the risk mitigation measures that can be implemented are systems such as OBWBS or systems to detect gross errors in the values entered. The progress made by the industry regarding these systems was not specified.

European Risk Classification Scheme (ERCS)

More recently, this safety issue, the use of erroneous parameters at take-off, was assessed by EASA through the European Risk Classification Scheme (ERCS), as required under Regulation (EU) N° 376/2014[61]. The preliminary results of this new classification scheme enabled EASA to build new risk portfolios as they are presented in their 2018 Safety Review[62]. ERCS is a scheme which gives a score to each occurrence given the severity of the possible accident and the supposed reliability of the remaining barriers. To build risk portfolios in which safety issues are prioritized, the scores of each occurrence are aggregated.

According to this initial work, the "*entry of aircraft performance data*" is not a priority as it is ranked as the 23rd safety issue (out of 47 listed safety issues). In the future, the overall aviation community and in particular operators, could benefit, in the scope of their SMS, from the publication of the detailed methodology used by EASA both to assess individual occurrences and to aggregate each occurrence assessment to arrive at a global score for a safety issue.

EASA explained that the data portfolio is subsequently reviewed to provide a more accurate representation of the actual risk and the most relevant safety issues. The review considers the increase/decrease of exposure to the relevant hazard, the effectiveness of existing barriers and the expected risk reduction by implemented safety actions. This analysis integrates the inputs of experts from industry and the Agency, through the Collaborative Analysis Groups (CAGs). The results of these reviews may lead to changes in priorities within the risk portfolio.

[60] https://www.easa.europa.eu/sites/default/files/dfu/218639_EASA_ASR_MAIN_REPORT_2018.pdf

[61] Regulation (EU) N° 376/2014 of the European Parliament and of the Council of 3 April 2014 on the reporting, analysis and follow-up of occurrences in civil aviation, amending Regulation (EU) N° 996/2010 of the European Parliament and of the Council and repealing Directive 2003/42/EC of the European Parliament and of the Council and Commission Regulations (EC) N° 1321/2007 and (EC) N° 1330/2007.

[62] https://www.easa.europa.eu/sites/default/files/dfu/218639_EASA_ASR_MAIN_REPORT_2018.pdf

Certification of the Airbus-designed Take-Off Monitoring (TOM) system for A380

The TOM system, which was developed by Airbus, was certified by EASA for the A380 in February 2018.

Regarding this improvement, EASA explained that:

- since the risk level does not reflect an "unsafe condition" as defined in AMC 21.A.3B(b) related to Regulation (EU) N° 748/2012[63], such a system could not be mandated (i.e. by an airworthiness directive);
- to call for a standardization directly based on this existing product is impossible since it would create a competitive advantage to one manufacturer detrimental to the market;
- to organize the promotion of this newly certified system had not yet been considered.

It was specified by EASA that the Airbus TOM system does not fulfil all the criteria that were established in the scope of the WG-94 related to the TOPMS.

[63] Commission Regulation of 3 August 2012 laying down implementing rules for the airworthiness and environmental certification of aircraft and related products, parts and appliances, as well as for the certification of design and production organisations.

4.2 Safety recommendations

Note: in accordance with the provisions of Article 17.3 of Regulation N° 996/2010 of the European Parliament and of the Council of 20 October 2010 on the investigation and prevention of accidents and incidents in civil aviation, a safety recommendation in no case creates a presumption of fault or liability in an accident, serious incident or incident. The recipients of safety recommendations report to the authority in charge of safety investigations that have issued them, on the measures taken or being studied for their implementation, as provided for in Article 18 of the aforementioned regulation.

4.2.1 Uniformity of weight data handled

The scenario of the event highlights a lack of response from the crew to inconsistent weight and speed values. In general, international studies on the use of erroneous parameters have shown that the orders of magnitude are either little or not at all mobilized during the flight preparation. One of the reasons lies in the fact that the various notions handled, the associated units and the denominations used make for too many representations to be stored in working memory by crews. The values handled then lose their meaning, preventing any comparison with values already handled in an equivalent context.

The analysis pointed to the variety of weight data formats and denominations handled by the Air France crew during the flight preparation. Homogenization of the data between the media would make it possible to both facilitate simple equality checks and reduce the cognitive load. The goal is to give meaning to the numbers handled, to allow a better acquisition of the usual values and a more systematic use of orders of magnitude.

Consequently, the BEA recommends that:

- **Air France modify the media used (the flight file, the Loadsheet and the EFB interface) during flight preparation in order to increase the consistency between the different weight denominations, formats and units handled by the crews.**
  [Recommandation FRAN2018-016]

This problem may exist for other French operators.

Consequently, the BEA recommends that:

- **DSAC assess the need for other French operators to modify the media used (the flight file, the Loadsheet and the EFB interface) during flight preparation in order to increase the consistency between the different weight denominations, formats and units handled by the crews.**
  [Recommandation FRAN2018-017]

4.2.2 Operational procedures

The procedures in effect on Boeing 777 at Air France at the time of the serious incident had the same weaknesses as those highlighted by the studies published by the BEA, ATSB and NASA: very partial consideration of the operational constraints, handling of weight data in different formats, multiplication of checks, lack of an overall consistency check of the values used, and a lack of gross error checks.

Following the serious incident, modifications were made, clarifying certain sequences. These modifications in reaction to the event, while they introduce beneficial features, add further checks to already demanding procedures, the robustness of which must be assessed not only while they are being set up but also over time.

These elements highlight existing weaknesses in the design of suitable procedures and in their validation in a real situation (while they are being set up and during operation). AMC 20-25 is now a relevant framework and therefore an additional support for designing and validating procedures involving EFBs.

Consequently, the BEA recommends that:

- **Air France check, in operational conditions, the robustness of the procedures for calculating and entering take-off parameters in order to take into account the constraints inherent in the flight preparation phase.**
  [Recommandation FRAN2018-018]

4.2.3 Continuation of flight after occurrence of a serious incident

The four crew members made the decision together to continue the flight after the occurrence of the serious incident. The Co-pilot (PF), aware of having been affected by the incident, was relieved after the initial climb. After the cause of the mistake was identified, the Captain postponed any discussion of the incident to after landing in Mexico.

The TAIL STRIKE procedure required that they turn back in case of doubt. However, the circumstances of the flight show that the choice between continuing the flight and the decision to land was not easy. Without outside intervention, crews do not necessarily have sufficient hindsight to make a good decision after the occurrence of a serious incident. They must therefore be able to benefit from the help of an objective external opinion.

Consequently, the BEA recommends that:

- **Air France improve the provisions allowing crews to request outside help for decision-making regarding the continuation of the flight after the occurrence of an incident.**
  [Recommandation FRAN2018-019]

4.2.4 Protections against entering erroneous speeds on Boeing 777

The F-GUOC incident is the third low-speed take-off known to the BEA on a Boeing 777 where flight crews did not detect or understand the V SPEEDS UNAVAILABLE message. The message was not sufficiently salient and explicit and can be deleted directly by the crew. Boeing's operational documentation on the calculation of reference speeds and on the conditions in which the V SPEEDS UNAVAILABLE message is activated, is incomplete. It does not allow operators to assess the risks and develop robust procedures for the V SPEEDS UNAVAILABLE message. The requests from DSB and from two operators to Boeing to improve the FCOM documentation about this message were not followed up by Boeing.

In addition, the aircraft systems do not warn crews of the loss of protection preventing the entry of speeds below V1min, VRmin and V2min normally calculated by the FMS. In the F-GUOC event, as the system authorized the crew to enter the speed data, the crew thought that take-off was possible.

Consequently, the BEA recommends that:

- **Boeing, for all the concerned aircraft in service, update the operational documentation relating to the V SPEEDS UNAVAILABLE message, in particular to indicate the conditions in which the message is displayed, the consequences (loss of the protection against entering speeds below calculated V1min, VRmin and V2min) and the action to be taken by crews if the message is displayed.**
  [Recommandation FRAN2018-020]
- **Boeing, for all the concerned aircraft in service and as for Boeing 787, review the systems concerned so that they clearly alert the crew for as long as the calculation of the minimum take-off speeds (V1min, VRmin, V2min) and the associated protection are not available.**
  [Recommandation FRAN2018-021]

4.2.5 Management of this safety issue by civil aviation authorities

Over the last 15 years or so, several safety investigations and safety studies have been conducted worldwide on the use of erroneous parameters at take-off. In this scope, several safety recommendations were issued concerning On-Board Weight and Balance Systems (OBWBS), Take-Off Performance Monitoring Systems (TOPMS) or gross error detection/warning systems.

OBWBS

A working group was initiated in 2010 by EASA under the auspices of EUROCAE. In 2013, this group stated standardization was possible and necessary. It was only at the end of 2015, after the serious incident involving F-GUOC, that the group was reactivated with the new mandate to define the MOPS. Work is still in progress at the time of publishing this report; the timing of the associated RuleMaking Task (RMT.0116) has been revised several times in recent years.

TOPMS

From 2006 onwards, Transports Canada indicated that there was not any TOPMS type system that was suitable for use in aviation and that the industry was the best placed to take the lead to develop one. The research project established by Transports Canada in 2007 came to a standstill in 2009 due to the lack of appropriate funding. In 2012, EASA initiated a working group under the auspices of EUROCAE to study the TOPMS. In 2015, this group concluded negatively about the possibility of standardization. In the meantime, Airbus started to develop TOM which meets certain TOPMS criteria. EASA did not take this opportunity to reactivate the group or to assess the safety benefits of this system. TOM was certified by EASA in February 2018 for the A380.

Gross error detection/warning systems

In 2009, in response to several safety recommendations from the NTSB, the FAA released acceptable means of compliance applicable to new airworthiness approvals of Flight Management Systems (FMS), including features to detect the use of grossly erroneous parameters. However, it decided not to extend these new requirements to already approved FMS, considering that operators' policies (notably the cross-check method) were sufficient barriers. For its part, EASA did not conduct a review of the existing systems as the agency had suggested it would do in 2011 following the BEA's recommendation in 2008. However, gradually, several aircraft manufacturers and equipment manufacturers, based on different approaches, have developed systems complying, in part, with this need. As with the serious incidents in 2015 involving F-GUOC and in 2013 involving PH-BVG as well as, in 2009, a similar incident identified by the DSB, several accidents and serious incidents among those identified by EASA result from entering clearly erroneous parameters in the FMS, which such systems could have detected and more effectively brought to the attention of the crews.

The overall approach of the civil aviation authorities regarding the above mentioned systems has been to let the industry both decide on the development and certification of advanced systems, and to decide whether to standardize or not. The authorities did not closely monitor the progress made by the industry regarding design features to better protect against risks associated with erroneous take-off parameters. This did not allow these authorities to influence the timing of the standardisation activity, as evidenced by the recent postponements of the conclusions regarding the possibility to standardise OBWBS, and even less the timing of the introduction of systems which have already been developed. Even when the state of the art has become favourable to the introduction of new systems, authorities have remained little involved.

The authorities were not able to bring their influence to bear on the availability of new systems and when such systems were available, they were not able to promote their widespread installation in the fleets most exposed to this risk. Generally speaking, the aviation authorities were not able to create conditions which would facilitate the development, certification, and installation of these systems.

Authorities in charge of rulemaking, certification and continued airworthiness, as well as safety oversight in other domains, have started implementing ICAO Annex 19 requirements regarding safety management, in particular those related to State Safety Programs (SSP). This is the case for EASA. In the scope of the Preliminary Impact Assessment (PIA) carried out by EASA in 2016 (updated in 2017), of the three systems mentioned above, despite various examples of gross error detection/warning systems existing and despite Airbus already announcing the development of TOM, EASA only assessed the OBWBS.

The BEA fully understands that the authorities and the industry set priorities, even and especially when it comes to dealing with safety issues. In this sense, all the above observations must be considered with reference to the priority level of this particular safety issue rendered visible for the first time by EASA in 2018, in its new safety risk portfolios.

Nevertheless, it is commonly agreed that the use of erroneous parameters at take-off, because of the associated risk areas (loss of control in flight, runway excursion, collision with obstacles during take-off), might have catastrophic outcomes. Moreover, EASA, as well as other authorities, may have overestimated the robustness of operational barriers able to prevent the use of erroneous parameters at take-off and ensure recovery from its consequences.

Incidentally, despite EASA considering that current safety barriers (of operational nature) are inadequate and insufficient in the scope of its safety analysis, it considered in 2016 that the most effective strategy was the publication of a Safety Information Bulletin (SIB), pending the results of the EUROCAE working group regarding OBWBS. At the same time, EASA considered that available data was not sufficient to assess the expected SIB safety benefit at the European level. As a consequence, EASA limited its assessment to the expected safety benefit for an operator if it implements an adequate Flight Data Monitoring (FDM) system[64]. The result (70%) was mentioned in the PIA. This reasoning does not estimate the overall safety benefit of the SIB or of an adequate FDM system as recommended in the SIB, given the high proportion of operators that already have an adequate FDM system and their contribution to the total number of commercial flights. The BEA agrees with EASA on the fact that data has to be taken into account with precaution. However, based on this limited set of data, the overall benefit that can be attributed to the SIB would be 14%. The BEA considers that even if not accurate, this is an order of magnitude that EASA should take into account.

(64) It has to be noted that the SIB is not limited to FDM promotion.

The fragility of operational barriers has already been demonstrated by the BEA in its safety study released in 2008. Other safety investigation authorities have pointed out this fragility. The F-GUOC serious incident is an additional confirmation. Even if it is important to regularly guide operators or to raise their awareness of good practices (as done by EASA through AMC 20-25 or the SIB), fragility remains as operational and organisational contingencies still represent factors that could occasionally and locally jeopardize efforts to consolidate these barriers. Airlines operators must manage this risk conscientiously but cannot be expected to control it alone. As an example in the present report, actions taken by an operator following a first incident that did not prevent the operator from being involved in a second very similar incident are mentioned. Overestimating the capacity of operators and crews to preclude gross parameter errors by relying only on procedural barriers could compromise the assessment of the priority level of this risk and the intended safety benefit for the SIB.

Regarding this SIB, EASA suggests additional mitigation elements, in particular those related to aircraft systems. It has to be noted that the development of these systems is not the responsibility of the operators to which the SIB is addressed. Nevertheless, this is a first step to promote technology and it would be useful to provide operators with more details about products available for each type of aircraft.

For all these reasons, it could be reasonable not to wait for the results of the SIB performance monitoring and for the unknown future conclusions of the EUROCAE working group regarding OBWBS prior to drawing up a global action plan. In this respect, it would be necessary to assess the potential benefits of the different technologies among those available or to come. Then an informed decision could be taken in coordination with each type certificate holder regarding the most appropriate technology(ies) for the types of aircraft.

Consequently, the BEA recommends that:

- **EASA, in the scope of an update of its impact assessment, assess the safety benefit of TOPMS-type systems, taking into account, in particular, the existing systems (Airbus TOM).**
  [Recommandation FRAN2018-022]

- **EASA, in the scope of an update of its impact assessment, assess the safety benefit of gross error detection/warning systems, taking into account, in particular, existing systems (Airbus TOS, Boeing FMS/EFB messages and protections, Lufthansa Systems LINTOP, etc.).**
  [Recommandation FRAN2018-023]

- **EASA, in coordination with the FAA, incite manufacturers to develop, for commercial aeroplanes which are the most prevalent and the most exposed to this risk, systems adapted to the characteristics of each aeroplane family, providing increased protection against the use of erroneous parameters at take-off.**
  [Recommandation FRAN2018-024]

- **EASA inform European national aviation authorities and operators about systems which exist or which are being developed for each aeroplane family which are likely to provide increased protection against the use of erroneous parameters at take-off.**
  [Recommandation FRAN2018-025]

LIST OF APPENDICES

Appendix 1

Serious incidents and accidents identified by EASA relating to use of erroneous parameters at take-off

No.	DATE	MAKE/MODEL	REGISTRATION	LOCATION
1	24/08/1999	B767-300	OY-KDN	Copenhagen, Denmark
2	28/12/2001	B747-100F, Cargo	N3203Y	Anchorage, Alaska USA
3	14/06/2002	A330-300	C-GHLM	Frankfurt Main A/P, Germany
3	29/11/2002	B737-800	TC-APJ	Dortmund, Germany
5	11/03/2003	B747-300	ZS-SAJ	Johannesburg, South Africa
6	12/03/2003	B747-400	9V-SMT	Auckland, New Zealand
7	17/06/2003	MD88	TC-ONP	Groningen Airport Eelde, Netherlands
8	04/09/2003	A321	OY-KBK	Oslo Airport, Norway
9	22/10/2003	B747-100/200, Cargo	JA8191	Tokyo, Japan
10	25/12/2003	B727	3X-GDO	Cotonou, Benin, West Africa
11	04/03/2004	ILYUSHIN IL76, Cargo	UR-ZVA	Baku, Azerbaijan
12	14/07/2004	A340-300	F-GLZR	Paris Charles de Gaulle Airport, France
13	08/10/2004	MD11	N275WA	Anchorage, Alaska USA
14	14/10/2004	B747-200, Cargo	9G-MKJ	Halifax Int. Airport, Canada
15	23/04/2005	B737-800	TC-SKC	Stuttgart, Germany
16	24/08/2005	A340-300	LN-RKF	Shanghai Int. A/P, China
17	12/07/2006	ERJ190	C-FHIU	Edmonton, Alberta, Canada
18	10/12/2006	B747-400	F-HLOV	Paris Orly Airport, France
19	16/08/2008	B737-800	SU-BPZ	Paris Charles de Gaulle Airport, France
20	28/10/2008	A330-200	G-OJMC	Sangster A/P, Montego Bay, Jamaica (UK)
21	13/12/2008	B767	G-OOAN	Manchester, UK
22	20/03/2009	A340-500	A6-ERG	Melbourne Victoria, AU
23	01/09/2009	A320	LZ-BHC	Verona, Italy
24	12/12/2009	A340	G-VYOU	LHR, UK
25	29/04/2011	A321	G-NIKO	Manchester, UK
26	22/11/2011	B737	VH-TJL	Melbourne, AU
27	05/02/2012	A340	4R-ADG	LHR, UK
28	14/04/2012	B737-33A	G-ZAPZ	Chambery Airport, France
29	04/07/2012	A319	G-EZDN	Prague, Czech
30	16/04/2013	B767-200	XA-TOJ	Madrid-Barajas A/P, Spain
31	22/05/2015	B777-F	F-GUOC	Paris Charles de Gaulle, Airport, France

Appendix 2

Excerpt from the Before Start Procedure set up by Air France following the serious incident involving F-GUOC

Final loadsheet (ECD) . . . . Verified . . C, F/O

Complete the takeoff parameters on the OPT.

Compare TOW and MACTOW from ECD with TOGW
and CG from OPT . . . . C, F/O
Update the takeoff weight and CG if needed . . . . C, F/O
Complete the CDU Preflight procedure, Performance Data steps.

Announce the ZFW and CG from ECD C
PERF INIT page: enter the ZFW and CG if needed . . . . F/O
Announce the GR WT . . . . F/O
Compare the GR WT with TOW from ECD C
Announce the takeoff parameters from OPT and check
CDU entries C
THRUST LIM page enter: . . . . F/O
TO or TO1 or TO2 as needed . . . . F/O
Note: This operation is not allowed by Air France. The takeoff derate for TO1 and TO2 is set to 0% by Airline Policy.

SEL Temperature if needed . . . . F/O
CLB or CLB1 or CLB2 if needed . . . . F/O
TAKEOFF page 2: enter as needed EO ACCEL HT,
ACCEL HT, THR REDUCTION . . . . F/O
TAKEOFF page 1: enter FLAPS, CG, V1, VR, V2 . . . . F/O
CAUTION: **If TAKEOFF V Speeds fields stay blank, check for discrepancies between takeoff parameters.**

Consider previous calculated TAKEOFF REF Vspeeds
from CDU . . . . C,F/O
CAUTION: **If FMC Messages TAKEOFF SPEEDS DELETED, V-SPEEDS UNAVAILABLE appear, check takeoff parameters.**

Appendix 3

Similar incidents on Boeing 777-300

DSB Report taken from the 2016 Quarterly Report Aviation publication

Take-off with insufficient engine thrust, Boeing 777-300ER, PH-BVG, Amsterdam Airport Schiphol, 7 July 2013

Introduction

On 7 July 2013 at 17:27, a Boeing 777-300ER took off from runway 36C at Schiphol Airport. The engine thrust selected for the take-off was lower than was required for the weight of the aircraft. In addition, the reference speeds used for the take-off - such as the maximum speed at which the take-off can still be safely aborted (V1), the speed at which the aircraft begins to rotate before the flight (Vr), and the safe initial climb rate (V2) - were lower than is procedurally required for safe flight operations. Shortly after the take-off, the cockpit crew noticed the anomalous speeds and corrected them, after which the flight continued as normal.

The take-off of an aircraft with insufficient engine thrust whether in combination with insufficient reference speeds or otherwise - is referred to as a take-off performance incident. These incidents bring along an increased risk as they could result in the aircraft leaving the runway at a speed close to the stalling speed, tail contact with the runway or contact with or reduced clearance to other obstacles. Various safety studies show that take-off performance incidents regularly occur with all types of aircraft operated by a variety of airlines around the world.

The incident on 7 July 2013 was almost identical to a similar incident that occurred with the same airline and with the same type of aircraft in 2009. The fact that an incident repeated itself under comparable conditions was particular cause for the Dutch Safety Board to initiate an investigation.

Flight preparations

During the flight preparations, the cockpit crew programs data - such as the flight path - into the flight computers. During the incident flight, the crew consisted of three pilots: a Captain, a first officer and a second officer. It is not uncommon within the airline involved for the second officer to conduct the preflight duties while the Captain follows the preparations from the third seat in the cockpit. Approximately 15 minutes prior to departure, the Captain switched seats with the second officer. Once the loading schedule was passed on to the crew 5 minutes after the scheduled departure time, the final calculations could be made. These calculations include the required take-off thrust and the corresponding reference speeds based on the total aircraft weight provided.

During the investigation, it was found that the airline's published operating procedure did not specify independent input of the aircraft weights by multiple crew members. An independent judgement of the input and calculation process is the most important safeguard for the detection of input errors, and therefore for the prevention of incorrect calculations. In this case an input error had occurred.

What the procedure does enable is a comparison of the calculation results between the Captain's Electronic Flight Bag (EFB) and the first officer's EFB. However, to arrive at a matching outcome, the input variables must be identical. Both in this incident and the incident in 2009, a pilot mentioned an incorrect take-off weight and the other pilot used that weight, which resulted in the calculations no longer being independent, causing the failure of an important safety net.

Upon entry of the results of the take-off performance calculation into the Flight Management Computer (FMC), the computer did issue a warning that was not entirely understood by the crew and was subsequently ignored. This resulted in the failure of a second safety net.

The second officer, who had initially performed a correct calculation on the Captain's EFB, had been distracted by the need to give flight-safety instructions to the ground official who was travelling with the crew in the cockpit. As a result, the second officer restricted himself to comparing the results of the Captain and first officer's EFBs, but he did not notice the low programmed engine thrust and the corresponding low reference speeds.

As a result, all of the available procedural safety nets failed during the flight-preparation stage and the aircraft taxied to the runway with incorrect take-off performance parameters. After entering the V speeds into the FMC and commencement of taxiing, no procedural safety nets were available to the crew and the incorrect take-off performance calculations remained undetected.

Take-off from runway 36C

Once the take-off thrust had been selected, the incident became inevitable, but flight crew intervention was still possible to reduce the severity of the outcome. For the crew, the lower than normal acceleration was not sufficiently noticeable to abort the take-off. Due to the lower reference speeds, the rotation point on the runway more or less coincided with the normal rotation point. Shortly after the rotation, the aircraft did not become airborne straight away: this took a total of four seconds longer than for normal rotation. As the first officer was aware of the risk of a tailstrike and because the aircraft's tailstrike-prevention system intervened, the aircraft's tail did not touch the runway. The speed at which the aircraft left the runway was thus the minimum lift-off speed determined by the maximum angle of attack where tail contact with the runway was just avoided. After lift-off the first officer subsequently increased the speed to above the selected reference speed, as a result of which the aircraft's rate of climb was unwittingly increased to the minimum safe rate. Shortly afterwards, the Captain detected the input error and the flight operations proceeded as normal from that point onwards.

Flight recorders

Of the available flight recorders, only the flight-data records were available. The cockpit voice recorder had a recording capacity of two hours, and was therefore recorded over during the course of the 10-hour flight. No possibility to secure the recording was available to the crew. The cockpit voice recorder would have provided clarity regarding the exact circumstances that led to the input error. The Dutch Safety Board has repeatedly recommended to increase the recording capacity of cockpit voice recorders to enable more to be learned about incidents.

Investigation of a similar incident in 2009

On 31 August 2009, a similar incident took place involving the same type of aircraft and the same airline. The recommendations stemming from this investigation and the partial implementation of these recommendations were unable to prevent a reoccurrence of the incident. In this investigation, it was already concluded that adjustment of the procedures is not the way to prevent such incidents.

The emphasis should be particularly placed on the prevention of input actions and unnecessary retyping of results. By the time of the incident in 2013, no progress had yet been made in this respect.

The investigation of the 2009 incident identified that take-off incidents constitute a global and frequently occurring problem. Earlier investigations have repeatedly resulted in recommendations to aircraft manufacturers regarding the need for an electronic safety net to be developed that can identify serious errors in performance calculations entirely independently of the cockpit crew's actions.

Measures taken by the airline

Almost immediately following the incident in 2013, the airline in question adjusted its procedures to place even greater emphasis on independent calculation of take-off performance parameters by the cockpit crew. Parallel to this, the airline has switched to an external system that is, in most cases, able to conduct an independent check of the input variables. This system has proved effective for the rest of the fleet of the airline involved. However, this system has limitations, and cannot prevent take-off performance incidents in all cases.

Another significant change that was made was to conduct the take-off performance calculation earlier in the preparatory stage in order to prevent time pressure immediately prior to take-off.

Exploratory investigation

An initial exploratory investigation conducted by the Dutch Safety Board identified that take-off incidents frequently occur following a failure by the cockpit crew to follow or fully follow the available procedures. Various international studies have established that input errors are influenced by a large number of factors such as fatigue, distraction, time pressure and reduced concentration, and that no procedures are available that can prevent these factors from occurring in all cases.

The European regulator EASA is currently conducting two studies intended to investigate the feasibility of a system that measures the aircraft weight for every flight and a system that identifies gross input errors.

The internal investigation report by the airline involved regarding the take-off incident in 2013 has been extended to include procedures and distractions to the cockpit crew. This has been done to such an extent that the Dutch Safety Board does not consider further investigation of this incident to be necessary. This statement in the quarterly report signifies the conclusion of this investigation by the Dutch Safety Board.

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