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Takeoff with erroneous takeoff data, Embraer 195-E2

Learning to reduce the risk of using erroneous takeoff data

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The Dutch Safety Board

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

RECOMMENDATIONS

The use of erroneous takeoff performance data is a safety issue of general concern and not specific to any aircraft type. The European Union Aviation Safety Agency (EASA) expects aircraft software and systems to provide hard barriers against erroneous data entry in the future. In 2020, the Dutch Safety Board recommended EASA to develop requirements for onboard systems. However, technical solutions will take some time to be developed and implemented in regulation. In order to speed up the availability of technical and software onboard systems the aviation industry needs to develop technical solutions to prevent the use of erroneous takeoff data. This investigation concludes that Embraer's performance application tool can be improved such that misselections are less likely to occur or more easily detected. Embraer started development of these improvements which are expected to be implemented in 2024. Therefore, the Dutch Safety Board does not make a recommendation on this issue and encourages Embraer to continue developing improvements for the performance application tool. The investigation also shows that Embraer has no plans to develop onboard systems that provide hard barriers against erroneous data entry, whereas some other manufacturers do. Therefore, the Dutch Safety Board makes the following recommendation:

To Embraer:

1. To start the development of an independent onboard system that detects gross input errors in the process of takeoff performance calculations and/or alerts the flight crew of abnormal low accelerations for the actual aeroplane configuration as well as insufficient runway length available.

C.J.L. van Dam
Chairperson Dutch Safety Board

C.A.J.F. Verheij
Secretary Director

2 THE SERIOUS INCIDENT

2.1 Introduction

The Dutch Safety Board investigated the serious incident that occurred on 12 September 2021 in order to determine the factors that contributed to the occurrence. Thereby, this chapter addresses the first investigation question and presents contributing factors to the incident in order to learn from it and reduce the risk of using erroneous takeoff data.

The chapter presents a summary of the history of flight and the analysis of the serious incident. More details regarding the factual information can be found in Appendix D.

2.2 Factual information

The flight
On 12 September 2021, an Embraer 195-E2 with registration PH-NXD, was scheduled for a flight from Berlin Brandenburg Airport (EDDB, hereafter Berlin) in Germany to Amsterdam Airport Schiphol (EHAM, hereafter Schiphol) in the Netherlands. The scheduled departure time was 17.38 hours. The flight crew consisted of a captain and a first officer. The captain acted as pilot flying and the first officer as pilot monitoring. It was the third and last flight on the last day of the flight crew's four-day schedule.

Flight preparation
After a short break between flights, the crew began their flight preparations and they planned from which runway intersection to take off. The crew expected a takeoff from Runway 25R and, after some discussion, they both agreed that intersection L5 was suitable in the prevailing weather conditions. The crew members stated that they did their takeoff performance calculation independently from each other by using the ePerf[17] application on their Electronic Flight Bag (EFB). The pilots reported they compared the outcomes of their calculations: the takeoff mode, assumed temperature, flap position and takeoff speeds, see Table 1. They seemed to be realistic and within the range of what could be expected, according to the crew. After confirmation that the output parameters were identical, the data was entered into the Flight Management System (FMS).

17 Crew members are provided with an iPad, that is used as a portable Electronic Flight Bag (EFB). One of the installed applications on the iPad is Embraer's ePerf. ePerf is used for takeoff and landing performance calculations for Embraer aircraft.

Table 1: Calculated ePerf output parameters for takeoff from intersection K5 and the parameters that had to be calculated for intersection L5.

	K5	L5
T/O mode	TO-3	TO-3
Flaps	Flaps 1	Flaps 3
V_1	139 kt	120 kt
V_R	140 kt	121 kt
V_2	143 kt	124 kt
T_{ASS}	57 °C	35 °C

Takeoff

After the ground controller issued the taxi clearance, the flight crew taxied from their stand B12 via Taxiway C towards intersection L5. The captain selected takeoff power. The first officer, as pilot monitoring, noticed that the primary thrust indicator (N1) showed 75%. Although he considered this to be low, he believed it was correct. During the takeoff roll, he also felt the acceleration was slow and considered calling "full thrust". However, to avoid triggering the captain to abort the takeoff by a non-standard callout[18] he did not do this. The captain also thought that the aircraft accelerated slower than he was accustomed to. He attributed this to the variant type. According to him, the Embraer 195 E2 accelerates a little slower than the other variants he is used to. Moreover, the E2 is more automated than the other variants and he believed the selected thrust was correct.

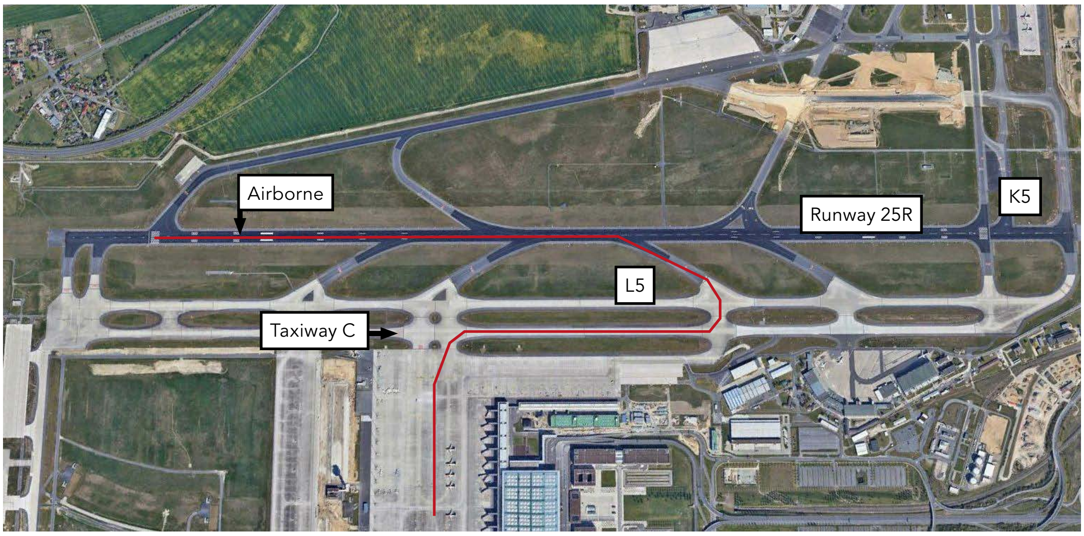

Figure 2: Aircraft route (red line), Runway 25R with taxiways towards intersections K5 and L5. (Source map: Google Earth)

18 It is common practice to abort the takeoff if a pilot makes a non-standard callout, because this means s/he observed something that could affect the safety of the flight.

The crew stated that during the first part of the takeoff roll, the red lights at the end of the runway were not visible because the runway is slightly curved. At a certain point, the aircraft reached the takeoff decision and rotation speeds and the red runway end lights became visible. The distance to the red lights gave both crew members the impression that the aircraft became airborne with little runway length remaining.

When the aircraft was stabilised during the climb, the crew discussed what happened during and before takeoff. After checking the parameters, they found that they had both selected intersection K5 instead of L5 in the ePerf takeoff performance calculation application. After recalculation, they found that the assumed temperature should have been 35 °C instead of 57 °C and that Flaps 3 should have been set instead of Flaps 1.

2.3 Performance calculation for wrong intersection

The aircraft took off from intersection L5 while the performance calculation was based on intersection K5. Therefore the engine's thrust and flap position were calculated and set for an available runway length (Take Off Run Available, TORA) of 3,385 metres, see Table 2. The acceleration of the aircraft to reach the calculated speeds V1 and Vr was also based on this distance. The actual TORA was 2065 metres, 1320 metres less. As a result, the acceleration of the aircraft was too slow to safely take off from intersection L5. This explains why the aircraft became airborne 443 metres[19] before the end of the runway (see Figure 2).

Table 2: available lengths of runway 25R from intersections K5 and L5.

Runway	Intersection	TORA	TODA	ASDA
25R	K5	3,385 m	3,445 m	3,385 m
25R	L5	2,065 m	2,125 m	2,065 m

After the occurrence the aircraft manufacturer calculated that the aircraft would have been unable to stop on the runway in case the takeoff had to be aborted at, or just before, V1, which would have resulted in a runway excursion. The Accelerate Stop Distance (ASD) under the circumstances was 2565 metres while the Accelerate Stop Distance Available (ASDA), was 2065 metres. Furthermore, in case of an engine failure after V1 the aircraft would likely not have been able to attain the required climb performance. Therefore, the safety margins were reduced during the takeoff.

19 Source: FDR data.
20 The available takeoff distance (TODA) consists of the available runway length plus the clearway of 60 metres.

A contributing factor to the occurrence was the selection error in the takeoff performance application (ePerf) by both pilots. As a consequence, the aircraft took off from intersection L5 - as the crew intended - while the performance calculation was based on intersection K5.

The actual available runway length was 1320 metres less than the runway length used in the calculation of the performance parameters. As a result, the set thrust setting was such that the acceleration of the aircraft was too slow to safely take off from intersection L5. The aircraft would likely not have been able to safely abort the takeoff at speeds close to V1. Safety margins were reduced during the takeoff.

2.4 Intersection selection error

Data entry into ePerf is a routine operation that is often repeated. Therefore, the pilots entered the required information quickly. All available runways and corresponding entry points of the selected airport were listed in a pull down menu. This listing was in numerical and alphabetical order and Runway 25R K5 was listed just above 25R L5, see Figure 3. Both crew members accidently touched and selected 25R K5 instead of 25R L5.

It is commonly understood that selection errors occur when working on a touchscreen with finger-touch interaction (tapping). Two factors explain the finger's inaccuracy with tapping. First, there is no system feedback about the location of the finger prior to completing selections by tapping the screen. Second, the 'fat finger' problem means that the finger is a large and relatively crude pointing device for small targets.[21] Items that are close to the desired target can be accidentally selected. Other incidents in which two crew members made the same error when selecting the runway and intersection have been investigated, namely the 2019 Nice incident[22] and the 2015 Lisbon incident.[23]

21 Cockburn, A., Ahlström, D., Gutwin, C., *Understanding performance in touch selections: Tap, drag and radial pointing drag with finger, stylus and mouse*, International Journal of Human-Computer Studies, 70(3), 2012.
22 AAIB, *Serious incident Airbus A319-111, G-EZBI*, 2020.
23 Dutch Safety Board, *Insufficient thrust setting for take-off*, 2018.

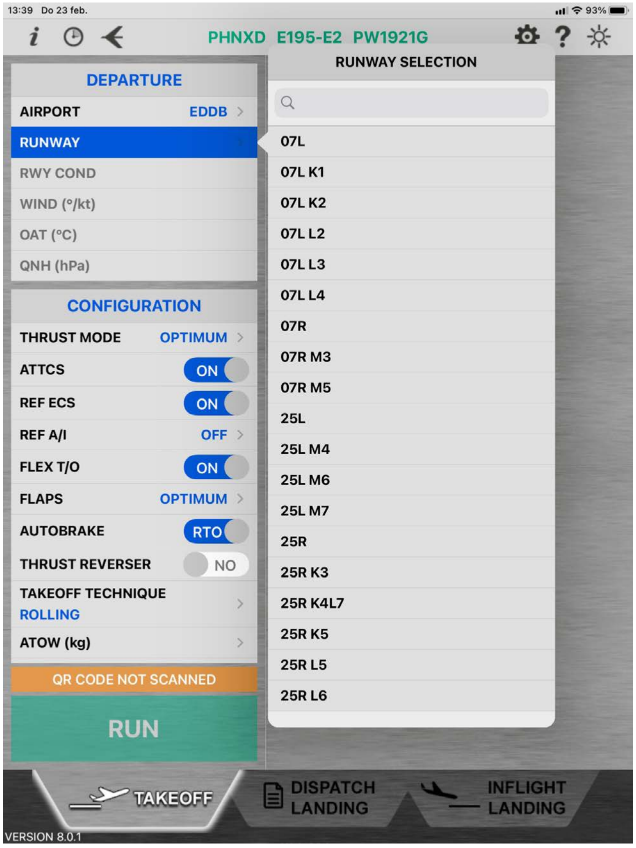

Figure 3: Page of electronic flight bag.

ePerf does not have a graphical representation of the selected takeoff starting point (the so called runway synoptic). A runway synoptic provides visual feedback after selection of the runway and intersection. According to the aircraft manufacturer, adding this function to the ePerf was considered in the user forum[24] in 2022, but it did not become part of the short or mid-term list of improvements for this application based on operators' priorities. This feature was discussed again in 2023 and placed on the short-term list of improvements. According to the aircraft manufacturer, the inclusion of a graphical representation of the runway is under development and expected to be incorporated in the software in 2024.[25] Furthermore, Embraer was in the process of implementing two other modifications of ePerf in order to reduce selection errors. First, a two-step intersection selection (first the runway, then the intersection on a separate menu) on ePerf is intended to decrease the number of selection errors (release Q3 2023). Second, highlighting the intersection used for calculation (inverse video display) in the output page header is intended to increase the chance of detecting a selection error (release Q3 2023).

24 Embraer organises yearly meetings with the operators that use Embraer EFB applications.
25 Embraer notes that the decision to develop this feature did not derive from this incident, but rather as result of a collaborative process with its operators.

The point from which pilots initiate the takeoff, was selected from a list containing all possible runway and intersection combinations, presented in a numerical and alphabetical order. Both intersections K and L were presented in ePerf, even though K intersections were not normally used by the operator. Runway 25R's intersections K5 and L5 were presented consecutively on the dropdown menu list, see Figure 3.

Both pilots selected the same wrong intersection in the application for takeoff performance (ePerf). When working on a touchscreen with finger-touch interaction, selection errors occur, among other things, due to a lack of system feedback about the location of the finger and the 'fat finger' problem.

The accidental misselection when working with a touch screen is common, especially if it is performed routinely and therefore quickly.

The application did not provide a runway synoptic feedback about the selected intersection and runway. The application contained intersections that are normally not used by the operator.

2.5 Error propagation

The Dutch Safety Board identifies three reasons why the selection error could propagate.

Crosscheck
The main barrier against selection errors in a performance calculation is a crosscheck between the calculations of both pilots. According to the operator's Operations Manual Part A, the flight crew must properly check input and output before accepting it for use. The crew reportedly compared the outcomes of their calculations, which had to be entered into the FMS: the takeoff mode, assumed temperature, flap position and takeoff speeds. As both pilots had reportedly selected the same wrong intersection, the outcomes were the same. In the investigation of the Board, it did not become clear whether the crew checked the input. While checking the input values, crew members may notice a potentially incorrectly selected parameter.

Expectation
Approaching Runway 25R, the aircraft passed the L5 intersection. The sign matched the crew's expectations, since they thought they had used L5 intersection for their takeoff performance calculation.

The calculated N1 became visible when the engines had been started and the system had calculated this value from all the data. When an N1 of 75% was presented, the pilots believed that the system had calculated this correctly. Calculations of the manufacturer showed that for a takeoff from L5 with flaps 1, N1 should have been 77,5%. In case of flaps 3 setting, the N1 should have been 74,8%. This shows that it was reasonable for the pilots to believe that 75% was calculated correctly.

The erroneous output data presented in ePerf did not raise the crew's attention, because it matched their expectations, which covered a wide range of values due to variant flying. During the four days of the pairing, the crew flew three different variants of the Embraer: Embraer 175, Embraer 190 and Embraer 195-E2. The flight crew was experienced in these variants and both crew members met the aim in the agreement of the Dutch Airline Pilots Association to fly each variant at least once every four weeks.[26] This agreement was based on the idea that the difference between this aircraft and the other variants requires regular crew exposure. Although switching between aircraft variants does not take much effort according to the crew, switching between Embraer aircraft variants may affect the feel for takeoff parameters (i.e. speeds and assumed temperatures) of a specific variant. The investigation could not determine whether this was a contributing factor in this occurrence. Switching between aircraft variants did play a role in the 2015 Lisbon incident[27] and the 2019 Glasgow incident[28].

Trust in the EFB
As a consequence of the optimisation algorithm in ePerf, the take-off configuration and or decision speeds may differ considerably under seemingly similar circumstances. As a consequence pilot's awareness and feel for numbers is reduced and a deviation from the required values will not easily be noticed. The Safety Board's interviews with the pilots made clear that it made sense for them to trust the data; after all, the EFB 'calculated it'. The trust of the crew in the calculated takeoff parameters, may be a contributing factor in the occurrence. This also played a role in the 2015 Lisbon incident[29].

The cross check did not reveal the selection error because the pilots likely focussed on the calculation outputs of the calculation, which did not differ as both pilots had reportedly selected the same wrong intersection.

The sign indicating intersection L5 could not reveal the selection error because the crew had this intersection in mind. Also the calculated N1 was within range of their expectations. Variant flying might have widened their range of expected performance parameters.

The crew's trust in the ePerf application may also have been a contributing factor in the occurrence.

26 The aim is to fly each variant at least once every four weeks. After 60 days without exposure on a particular variant Route instruction or Simulator training is mandatory.
27 DSB, *Insufficient thrust setting for take-off*, March 2018.
28 AAIB, serious incident Airbus A321-231, G-EUXJ, 2020.
29 DSB, *Insufficient thrust setting for take-off*, March 2018.

2.6 Pilot intervention

After the runway controller had issued the takeoff clearance, the flight crew lined up on the runway without stopping and selected takeoff power. Both crew members perceived a slower, but not unusual acceleration than expected.

The pilot flying thought slow acceleration was due to the difference between aircraft variants; he thought it was normal for the Embraer 195-E2 and believed that the thrust was calculated correctly. The pilot monitoring thought about giving the command "full thrust". He did not do this, because he wanted to avoid triggering an unnecessary aborted takeoff. Pilots normally reject the takeoff for irregularities before V1 and do not select full thrust.

The crew realised something was wrong when the red lights at the end of the runway had become visible and the V1 and VR speeds were reached.

It is a well-known phenomenon that crew members do not select full thrust when the aircraft's acceleration is less than expected. Full thrust was selected in one out of 23 occurrences involving the use of erroneous takeoff data, which were investigated by accident investigation boards in the period 2013-2021.[30] A study by the AAIB[31] into the human factors behind this phenomenon concluded: '*In summary, the application of more thrust was not a trained, natural or dominant response, whereas inaction on the thrust levers would be familiar and probably dominant. It is likely that many crews would react in the same way that the incident crew did, given the same circumstances.*' Some of the human factors which were mentioned in the study were applicable to this incident:

1. Approaching the red lights at the end of the runway created a visual picture that would have been an indirect acceleration clue. However, due to the curvature of the runway and the human visual system generally being insensitive to the rate of acceleration, this clue did not develop above a triggering threshold.
2. Flight crews have a poor perception of time during takeoff as they are concentrating on other matters. Therefore, the pilots could not differentiate time to reach V1 from other takeoffs. Furthermore, acceleration rates vary due to the everyday variation in aircraft weight, runway and performance conditions.
3. The flight crew rarely added thrust settings during training, because most types of takeoff events do not require thrust adjustments. Moreover, it is unnatural and counter-intuitive to add thrust – and increase speed - when the red lights at the end of the runway are fast approaching.

30 Appendix F provides an overview of these occurrences.
31 AAIB, *Report on the serious incident to Boeing 737-86J, C-FWGH Belfast International Airport on 21 July 2017*, 2018. https://www.gov.uk/aaib-reports/aircraft-accident-report-aar-2-2018-c-fwgh-21july-2017

The pilots did not select full thrust.

Not adding thrust is the dominant response for pilots as thrust should normally not be changed during takeoff. Furthermore, it is common that pilots are not required to add thrust for takeoff events in training situations.

2.7 The flight crew

The flight crew were properly licensed and qualified to perform the flight. The incident flight was the last flight on the fourth day of a flight pairing that consisted of three flights on the first day, four flights on the second and third day and three flights on the last day. At the end of the third day, the crew felt uncomfortable to continue because of work pressure and operational disruptions. They contacted crew control to discuss the problems they had experienced, but felt pressured to perform the three flights the next day. They decided to evaluate their level of fatigue after a night's sleep in Basel. In the morning, they felt sufficiently rested to perform the last three flights. The investigation did not further examine to what extent fatigue played a role or contributed to the occurrence of the incident.

During the turn-around in Berlin the crew had sufficient time preparing for the return flight to Schiphol as their flight was on schedule and there were no last-minute changes. They felt no need to rush and consequently did not experience any operational pressure.

The Board did not find any evidence that factors, such as rush, operational pressure, last minute changes and distraction, played a role. The investigation did not further examine to what extent fatigue played a role.

2.8 Technical systems

In the longer term, aircraft software and systems are expected to provide hard barriers against the use of erroneous data. As most aircraft currently in operation, the Embraer aircraft are not equipped with a system that detects erroneous takeoff data before or during takeoff. Therefore, these aircraft do not alert the flight crew during takeoff of abnormally low accelerations for the actual aeroplane configuration, nor for insufficient runway length available in case of intersection takeoffs. Embraer has stated that they are not currently developing such a system.

In October 2020, the Dutch Safety Board published the report 'Erroneous takeoff performance calculation, Boeing 777', in which both the manufacturer and the regulator received a recommendation.

The following recommendation was issued to the European Union Aviation Safety Agency and the Federal Aviation Administration:

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

EASA initiated a new rule making task (RMT) regarding takeoff performance parameters and position errors for large aircraft. The industry, including Embraer, is involved in the working group. To date, the European Union Aviation Safety Agency has not decided on rulemaking activities regarding their Best Intervention Strategy (BIS) for erroneous takeoff data.

The following recommendation was issued to The Boeing Company in 2020:

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

The Boeing Company has developed a Takeoff Performance Alert (TPA) feature consisting of an algorithm and flight crew alert, which is being evaluated for certain existing and future Boeing models. Further testing and evaluation of the TPA function will continue into 2023 and beyond with on airplane testing anticipated in 2024.[32]

Airbus also developed some technical systems for takeoff surveillance and monitoring (TOS and TOM) that have been certified by EASA.[33] The TOS2 function that checks the available runway length before takeoff is available on the Airbus A320, A330 and A350 types. The TOM function that checks the acceleration during takeoff is available on the Airbus A350 and A380 types.

32 Source: Boeing update letter in response to the recommendation (December 2022).
33 The website of the manufacturer provides more information about the systems: https://safetyfirst.airbus.com/takeoff-surveillance-and-monitoring-functions/

2.9 Conclusions

A contributing factor to the occurrence was the selection error in the takeoff performance application (ePerf). As a consequence, the aircraft took off from intersection L5 - as the crew intended - while the performance calculation was based on Intersection K5. The actual available runway length was 1320 metres less than the runway length used in the calculation of the performance parameters. As a result, the set thrust setting was such that the acceleration of the aircraft was too slow to safely take off from intersection L5. The aircraft would likely not have been able to safely abort the takeoff at speeds close to V1. Safety margins were reduced during the takeoff.

Both pilots said that they selected the same wrong intersection in the ePerf application. Contributing factors to the selection error were the following:

- The accidental misselection when working with a touch screen is common, especially if it is performed routinely and therefore quickly. When working on a touchscreen with finger-touch interaction, selection errors occur, among other things, due to a lack of system feedback about the location of the finger and the 'fat finger' problem. The misselected item is often close to the intended item.
- The application did not provide visual feedback about the selected intersection and runway (runway synoptic).
- The pull down menu contained intersections that are normally not used by the operator.

The cross check did not reveal the selection error, because the pilots likely only focussed on the calculation outputs of the calculation, which probably did not differ as both pilots had reportedly selected the same wrong intersection. The sign indicating intersection L5 and the available runway length could not reveal the selection error either, because the crew had this intersection in mind. Also the calculated N1 was within range of expectation.

The trust of the crew in the calculated values by the performance calculation application may also have been a contributing factor to the occurrence. On top of that, it is the dominant response, common and trained, that pilots do not add thrust during the takeoff.

The Board did not find any evidence that factors such as rush, operational pressure, last minute changes and distraction, played a role.