Loss of Directional Control during Landing Roll at Turku Airport on October 25, 2017

L2017-05

SYNOPSIS

Pursuant to section 2 of the Safety Investigation Act (525/2011), the Safety Investigation Authority of Finland (SIAF) decided to investigate an incident in which an airliner experienced loss of directional control at Turku airport on October 25, 2017. The purpose of a safety investigation is to promote general safety, the prevention of accidents and incidents, and the prevention of losses resulting from accidents. A safety investigation is not conducted in order to allocate legal liability.

Air traffic control officer (retired) Pekka Orava was appointed the investigation team leader. Team members were airline pilot Mika Kosonen, Doctor of Science (economics) and Master of Arts (psychology) Petri Koistinen, and special investigator Timo Naskali. The investigator-in-charge was Chief Air Safety Investigator Ismo Aaltonen.

The Transportation Safety Board (TSB) of Canada appointed an accredited representative for the investigation, and the airplane manufacturer Bombardier appointed an advisor for the TSB representative. The Air Accident Investigation Unit (AAIU) of Ireland and the Swedish accident investigation authority SHK (Statens haverikommission) appointed accredited representatives for the investigation pursuant to Annex 13 to the Convention on International Civil Aviation. Pursuant to Regulation (EU) No 996/2010 on the investigation and prevention of accidents and incidents in civil aviation, the European Aviation Safety Agency (EASA) appointed a technical advisor for the investigation. Pursuant to section 12 of the Safety Investigation Act, the SIAF decided on the participation of the authorized and accredited representatives and advisors in the investigation.

The safety investigation examines the course of events, their causes and consequences, search and rescue actions, and actions taken by the authorities. The investigation specifically examines whether safety had adequately been taken into consideration in the activity leading up to the accident and in the planning, manufacture, construction and use of the equipment and structures that caused the accident or incident or at which the accident or incident was directed. The investigation also examines whether the management, supervision and inspection activity had been appropriately arranged and managed. Where necessary the investigation is also expected to examine possible shortcomings in the provisions and orders regarding safety and the authorities' activities.

The investigation report includes an account of the course of the accident, the factors leading to the accident, and the consequences of the accident as well as safety recommendations addressed to the appropriate authorities and other actors regarding measures that are necessary in order to promote general safety, prevent further accidents and incidents, prevent loss, and improve the effectiveness of search and rescue and the actions of other authorities.

An opportunity is given to those involved in the accident and to the authorities responsible for supervision in the field of the accident to comment on the draft investigation report. These comments have been taken into consideration during the preparation of the final report. A summary of the comments is at the end of the report. Pursuant to the Safety Investigation Act, no comments given by private individuals are published.

The investigation report has been translated into English by TK Translations.

The investigation report and its summary are published on the SIAF's internet page at www.sia.fi.

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CONTENTS

1 EVENTS

1.1 Sequence of Events

On Wednesday October 25, 2017, a Bombardier CRJ900 airplane was operating as Scandinavian Airlines (SAS) flight SK4236 from Stockholm, Sweden, to Turku, Finland, carrying 88 passengers and 4 crew members. It landed at Turku at 2024 h[1]. After touchdown, the airplane traveled along the runway at 151 kt (280 km/h) groundspeed. It did not decelerate as anticipated after touchdown. During the landing roll it entered a skid and started to drift towards the right edge of the runway with the nose pointing to the left of track.

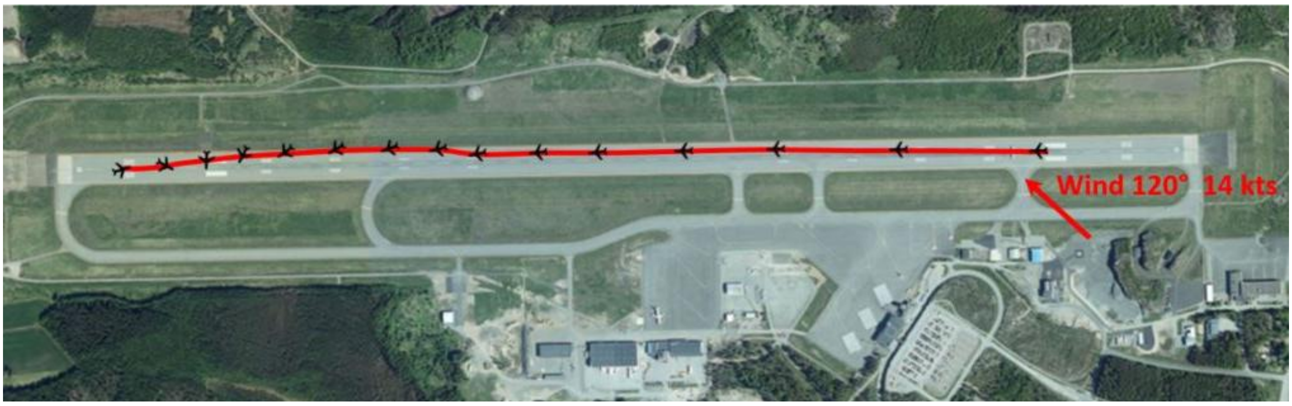

Figure 1. Aircraft track as derived from global positioning system (GPS) and heading information. (Photo: Orthophoto ©National Land Survey of Finland 6/2018, overlays: SIAF)

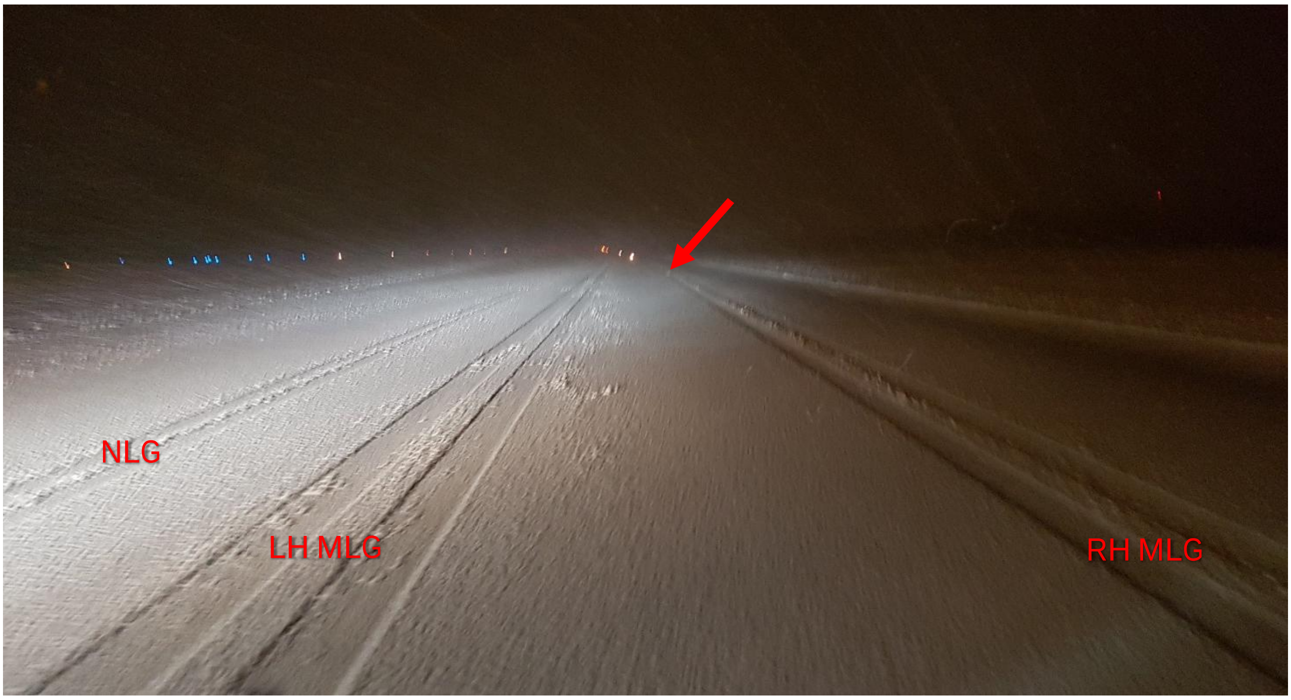

Figure 2. The tracks left by the left main (LH MLG), right main (RH MLG), and nose (NLG) landing gear as the skidding airplane was veering towards the runway edge lights, as seen approximately 35 min after landing. The red arrow shows the location of the first broken light. Intact lights are visible further down the runway in the center of the photo. (Photo: Finavia, annotations: SIAF)

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1 The times given in this report are Finnish daylight saving time (UTC + 3 h).

Approximately 1,200 m from touchdown, the skidding airplane began to veer to the right towards the edge of the paved area. It impacted and broke five runway edge lights. The minimum distance between the right mainwheel tires and the unpaved area was less than 0.5 m. The airplane then started to rotate to the left. When it was at right angles to the runway heading it was moving at 42 kt (78 km/h) groundspeed. It came to a halt next to the runway centerline 2,050 m from the initial touchdown point, having rotated 196° counter-clockwise from the initial direction of travel. The distance from the final position to the runway end was approximately 160 m.

Figure 3. A snapshot from the flight data recorder -derived animation shows the skidding airplane veering off the runway. At this point, groundspeed is approximately 170 km/h, and the airplane tracks as indicated by the yellow line that is based on the locations of GPS points obtained from the recording. The actual paved area extends beyond the white runway edge line, but this is not shown in the picture. The tires did not leave the paved area. (Photo: Insight™ ProView)

1.1.1 Flight Crew Actions

On the day of the occurrence, the captain's roster began in Copenhagen, Denmark, with an operator's proficiency check (OPC) in a simulator. After the OPC, the captain deadheaded to Stockholm. Flight SK4236 was the first sector in the captain's roster as a crew member. The first officer had already flown a sector from Vilnius, Lithuania, to Stockholm so flight SK4236 was the first officer's second sector in the day's roster. During the preflight briefing, the crew noted that a weather front was approaching Turku. They considered a very-high frequency omnidirectional range (VOR) runway 08 approach, but given the low cloud base thought it unlikely that they would establish the required visual contact with the runway by the minimum descent height. They noted that runway 26 tailwind component was close to 10 kt, which is the maximum for the CRJ900. They selected Helsinki as the destination alternate aerodrome. The captain decided to uplift 500 kg more fuel than previously calculated, which brought the ramp fuel load to 4,500 kg. The crew was aware of the fact that the airplane would be close to the maximum weight for a landing at Turku. Before departure, the crew used trained decision-making models (DODAR[2], TEM[3]) in order to prepare for the upcoming situation. The first officer conducted an approach briefing and analyzed the anticipated threats, which included darkness, low cloud base, wet runway, and difficult wind conditions.

The crew made an initial contact with Turku air traffic control (ATC) approximately 20 min before landing and received the latest information on runway and weather conditions. ATC reported friction as medium, deposits of 2 mm of slush over each third of the runway, and wind from 120° at 16 kt. The captain inquired ATC about runway 26 tailwind component, which was reported as 12 kt.

The crew noted this was above the permitted maximum, but since the tailwind component was close to the limiting value they decided to continue runway 26 instrument landing system (ILS) approach and land, provided the tailwind component would be 10 kt or less. Should the tailwind exceed the maximum they would execute a missed approach and divert to Helsinki. They therefore requested ATC for an alternative missed approach clearance to 5,000 ft and also prepared to enter a hold. Approximately 8 min before landing, the captain studied the airplane's performance calculations against the reported conditions. The captain calculated that the maximum performance limited[4] landing weight for the prevailing conditions was 36,000 kg. The maximum structural landing weight of the CRJ900 is 34,065 kg. The crew members did not cross-check the calculations and continued the approach as planned.

When the airplane was 500 ft above ground level (AGL), ATC reported wind from 120° at 14 kt and a tailwind component of 10 kt. The captain took control and stated they would land.

The captain disengaged the autopilot at 121 ft AGL. The captain crossed the runway threshold at a higher-than-normal descent rate in order to aim the airplane at the correct touchdown point. The airplane crossed the threshold[5] at 151 kt indicated airspeed.

Touchdown occurred at a correct point within the aiming point markings at 151 kt groundspeed and 148 kt airspeed. Vertical acceleration at touchdown was 1.95 g. The captain selected full reverse thrust immediately after touchdown. At the same time the spoilers which are increasing aerodynamic braking and reducing the lift were activated. Due to a firm touchdown, weight on the landing gear lightened to such an extent that the airplane systems sensed an airborne condition. The design of the CRJ900's full authority digital engine control system (FADEC) incorporates a logic that inhibits thrust reverser operation above idle power when the airplane is airborne. Consequently, reverse thrust was unavailable and FADEC commanded the engines to reverse idle. Although full reverse thrust remained selected until the airplane entered the skid, the engines remained at reverse idle.

The captain initiated manual braking upon nosewheel touchdown. However, after touchdown, the wheels started hydroplaning and did not spin up to the normal rotational speed. A function in the anti-skid system, which is designed to prevent wheel locking during brake application, inhibited the system, and the wheels locked after 5 s from touchdown.

The captain steered the airplane at first with the rudder and applied constant upwind, i.e., left aileron. 6 s after touchdown, the captain indicated an inability to control the airplane. The captain released the control wheel and attempted to regain control using nosewheel steering

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2 DODAR (diagnose, options, decide, act/assign, review) is a decision-making model for teamwork in which the skills and knowledge of all team members are pooled in order to solve a problem and select a course of action. In this way all members will have identical information of the factors affecting decision-making and of the selected course of action.

3 TEM (threat and error management) is a decision-making model in which threats are previewed and addressed.

4 The CRJ900 has a maximum structural and maximum performance limited landing weight, of which the more restrictive is observed.

5 The beginning of that portion of the runway that is available for landing

and the rudder. The captain also stated that a FADEC FAULT message had displayed; this resulted in reverse thrust remaining at idle. 13 s from touchdown, the first officer also initiated braking, assuming that the captain was not applying the brakes or the brakes were inoperative. The first officer did not notify the captain of the brake application. The rate of deceleration was low due to the lack of reverse thrust and the fact that the locked wheels were in a hydroplaning condition. Due to the loss of lateral grip, the airplane entered an uncontrolled left yaw 24 s after touchdown. The captain attempted to counter the yaw by applying right rudder until the rudder reached full right deflection.

Approximately 30 s after touchdown, at 2024 h, the first officer transmitted a mayday call and a distress message on the ATC frequency, believing the airplane was skidding and was about to depart the runway. The message overlapped a taxi clearance that the controller was issuing. The first officer repeated mayday and the message 10 s later, and 48 s after touchdown told ATC that the airplane had stopped.

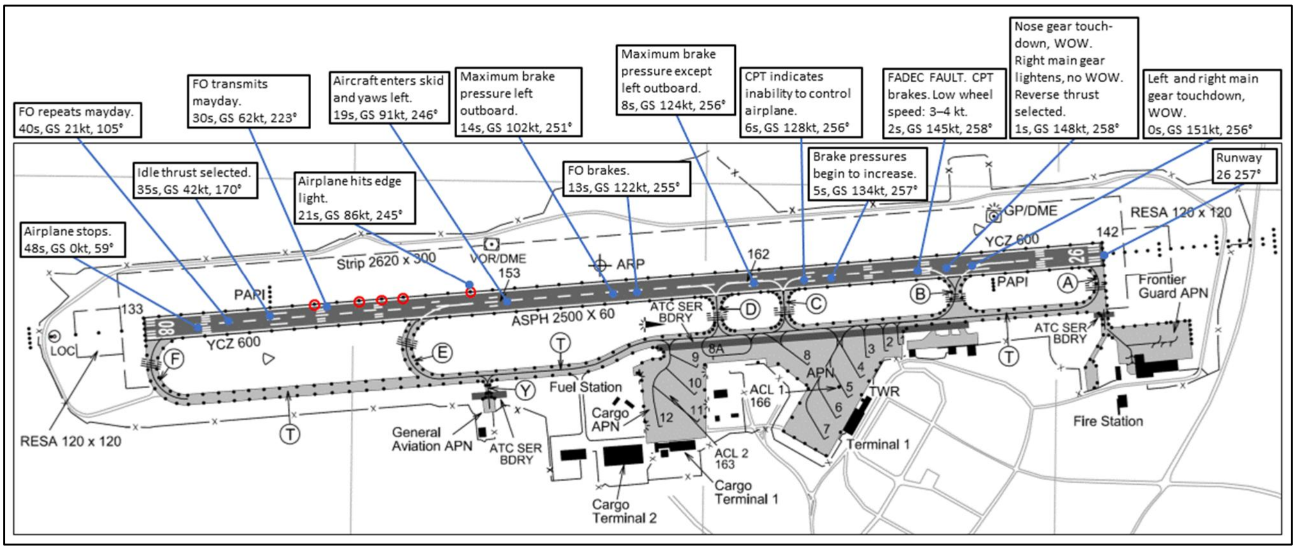

Figure 4. Significant events during the landing roll. The red circles indicate the broken runway edge lights. The bottom line(s) in each box indicates time from touchdown, groundspeed, and heading (WOW = weight on wheels, GS = groundspeed, CAPT = captain, FO = first officer). (Base map: ©ANS Finland Oy, overlays: SIAF)

1.1.2 Air Traffic Control Actions

Air traffic was slow during the afternoon shift (1345–2100 h) at Turku ATC facility. At the time of the occurrence, the facility was manned by a trainee controller, who was at the final stages of training, and a training controller. The trainee controller occupied the controller's workstation under the training controller's supervision.

Noting the deterioration in weather, Turku ATC asked the area control to hand over flight SK4236, which had departed from Stockholm, to Turku ATC frequency as soon as practical. In this way the flight crew would receive timely information on the runway and weather conditions at Turku. After receiving an approach clearance, the flight crew requested wind data, and the trainee controller told them that the wind was from 120° at 14 kt with an 11 kt tailwind component. The crew had previously indicated to ATC that the maximum permitted tailwind component for the flight was 10 kt. Almost immediately after issuing flight SK4236 a landing clearance the trainee controller notified the crew of the reduction of the tailwind component to 10 kt, and therefore the crew considered it appropriate to continue the approach to land on runway 26.

The trainee controller and training controller did not observe that the airplane had entered a skid upon landing. They reported the landing time and cleared the flight to taxi to the apron.

1.1.3 Aerodrome Maintenance Actions

Figure 5. This close-up was taken on the apron approximately 50 min after landing. The airplane taxied into this position and stopped approximately 15 min after landing. No significant amount of fresh snow has fallen on the underwing areas, and by examining the track depth it can be estimated that the slush was over 10 mm deep at the time of the landing. Ground temperature expedited the transformation of snow into slush. (Photo: Police)

The aerodrome maintenance unit had the normal manning of three persons. Light sleet that had fallen during the day changed to light snow at 1845 h. The intensity of snowfall increased to moderate at 1915 h. Due to the rapidly worsening weather, maintenance called an additional person to report for duty at 1920 h. Maintenance inspected the runway and issued SNOWTAMs[6] at 1935 and 2003 h. Runway conditions changed between these SNOWTAMs due to snowfall. The estimated depth of slush on the runway was 2 mm, and friction over each third of the runway was medium. The estimated landing time of flight SK4236 was 2030 h. Maintenance estimated that the present runway conditions were sufficient for the landing of flight SK4236 and the subsequent departure of flight AY217 to Maarianhamina and planned to commence runway sweeping after flight SK4236 had landed and flight AY217 had departed.

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[6] A special series NOTAM (notice to airmen) notifying, by means of a specific format, the presence or removal of hazardous conditions due to snow, ice, slush or standing water associated with these deposits on the movement area.

1.2 Alerting and Rescue Operations

1.2.1 Flight Crew Actions

The flight crew set the parking brake after the airplane had stopped. The captain ordered the cabin crew to prepare for an evacuation by calling “cabin crew at stations” and told the first officer to run the On Ground Emergency checklist.

The crew assessed the situation as apparently normal, and the captain decided that an immediate evacuation was not required. The captain canceled the previous call to prepare for an evacuation by calling “all normal” and then explained to the passengers that the runway was slippery and the situation was being investigated.

The captain judged that the airplane was taxiable, but ATC told the flight to hold position and wait for the rescue units. The flight crew discussed the occurrence and reviewed the sequence of events. They agreed that the wind and speed had been within limits, and a FADEC FAULT message for both engines had displayed after touchdown.

Since no external damage was noted, the crew requested a taxi clearance to the apron. At 2031 h, 7 min after the airplane had stopped, the controller cleared the flight to taxi to the apron. During taxi, the first officer brought up the possibility of a tire damage. The captain decided to leave the flaps in the “down” position.

1.2.2 Air Traffic Control Actions

Upon receiving the first officer's mayday call[7] and the associated distress message, the training controller, as the duty officer, occupied the controller's workstation. The trainee controller assumed assistant's duties, which included answering phone calls and the recording of events as required. At 2025 h, the controller alerted the aerodrome rescue and fire fighting (ARFF) service of an aircraft accident, and at 2026 h made an emergency call to the emergency response center (ERC) at Turku. The controller also alerted area control in accordance with a standing procedure, and area control then alerted the Aeronautical Rescue Coordination Center (ARCC).

After learning that the airplane had stopped, the controller told the flight to hold position and explained that rescue units were on their way to investigate the situation. The controller was in radio contact with the aerodrome maintenance supervisor (call sign LENTO P3) while the line to the ERC was open. The ERC dispatcher thereby learned that there were no apparent injuries and the airplane was undamaged. Since the flight crew also considered the airplane undamaged, the controller cleared the flight to taxi to the apron. The controller asked the flight crew to report the number of persons on board (POB), and the crew replied that the POB was 88. At 2031 h, the controller called the ERC again and said that the POB was 88, and also advised that the airplane was taxiing to the apron and “all was okay.” However, the correct POB was 92, consisting of 4 crew members and 88 passengers.

1.2.3 Aerodrome Rescue and Fire Fighting Service Actions

Maintenance unit personnel were monitoring the ATC frequency and heard the distress message from flight SK4236, which was immediately followed by an aircraft accident alarm raised by the controller. They immediately manned two rescue vehicles. A rapid intervention vehicle (AR1141) was cleared by ATC to proceed via the runway to the airplane. A heavy foam tender (AR1142), driven by LENTO P3 – who had initially assumed the incident commander's

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7 Mayday call is explained in aviation regulation GEN M1-8 6.2.

duties – was cleared to proceed to the airplane via the main taxiway and link F. While still on the taxiway, LENTO P3 observed that the airplane was stationary on the runway with its nose facing the direction of arrival.

The airplane's engines were running as the rescue vehicles were making their approach. The rescue crew members checked the general condition of the airplane without leaving their vehicles. LENTO P3 advised ATC that there was no apparent external damage to the airplane. The airplane then taxied to the apron as cleared by ATC. While accompanying the airplane, the rescue crew members noted that two runway edge lights were dislocated and notified ATC of the damage. After the airplane had stopped on the apron LENTO P3 and the on-duty fire officer boarded the airplane to assess the condition of the crew and passengers. They also interviewed passengers on the way to the terminal building and in the baggage claim area. The fire officer instructed two check-in staff then present in the terminal to observe the passengers and inquire about their well-being. By that time, several passengers had already left the airport. The rescue vehicles remained in attendance until all passengers had deplaned.

1.2.4 Emergency Response Center Dispatcher Actions

The air traffic controller called Turku ERC direct at 2026 h. At an early point in the call, the controller started receiving additional information from the flight crew and asked the dispatcher to hold the line. Approximately 36 s after initiating the call, the controller told the dispatcher that an aircraft accident had occurred at the airport. The call was interrupted again when ARFF advised that rescue units were deploying to the airplane and requested information on the target. The controller then resumed the call, reporting that a passenger-carrying airliner had spun on the runway on landing and told the dispatcher that the airplane was apparently undamaged and there were no known injuries. The dispatcher inquired about the number of airplane occupants, but this was not known to the controller.

The dispatcher notified the on-duty supervisor of the situation. Based on the emergency call information and using a risk assessment model they classified the event as a minor aircraft accident. Paramedic units were not alerted. At 2030 h, 4 min from the beginning of the emergency call, the ERC issued an alert.

Table 1. Units alerted by ERC

Call sign	Alerted	At target	Location	Type
RVSL11	2030:06	2046:41	Lieto fire station	Fire truck
RVSIT3	2030:10	2041:15	Lieto fire station	Command vehicle
RVST13	2030:13	2046:02	Turku central fire station	Water tender
RVST41	2030:18	2035:09	Kärsämäki regional fire station	Fire truck
PVS219	2030:39	Not known	Southwestern Finland Police Department	Police vehicle

The controller augmented occurrence information by relaying POB to the ERC.

At 2030 h, the ERC dispatched patrol #219 of the Southwestern Finland Police Department to the airport.

1.2.5 Rescue and Paramedic Operation

At 2027 h, the on-duty fire officer (ITÄ P3) at the Southwestern Finland Rescue Department received via the nationwide public safety network a radio call from LENTO P3 advising that

ARFF units were on station next to an airplane. The officer-in-charge (RVSP2), who was monitoring radio communications, also contacted ITÄ P3 and requested that RVSP2 would be kept up to the situation and that ITÄ P3 verify the assignment. At 2030 h, an alert of *a minor aircraft accident* came in.

LENTO P3 told ITÄ P3 that the ARFF units were escorting the taxiing airplane to the apron. As information on the situation was sketchy, ITÄ P3 directed all rescue units to proceed to the airport. ITÄ P3 was unaware of the fact that paramedic units had not been alerted.

ITÄ P3 arrived at the airport at 2041 h, when the passengers were already moving from the airplane into the terminal building. The crew of RVST41 of the Southwestern Finland Rescue Department had arrived at the airport at 2035 h. Together with aerodrome ARFF personnel they interviewed the crew and inquired passengers about their well-being and reactions to the event. The on-duty fire officer advised check-in staff present in the baggage claim area to observe the passengers' condition and interview the passengers. However, several passengers had by that time left the terminal.

ITÄ P3 decided that the most appropriate course of action was to have paramedics assume responsibility for checking the passengers. Therefore, at 2055 h, ITÄ P3 called the on-duty paramedic field supervisor (VSL4) of the Southwestern Finland Health Care District and inquired about the time of arrival of paramedic units at the airport and of the number of units dispatched. ITÄ P3 reported that 92 persons were involved.

VSL4 was unaware of the event and advised ITÄ P3 that paramedic units had not been alerted. Since the situation had practically ended and there were no injuries, ITÄ P3 assessed that the rescue department would be able to check the passengers without paramedics' assistance.

VSL4 issued an advance notification to Turku University Hospital and told them to discontinue all non-critical patient transport within the area of the Southwestern Finland Health Care District.

The rescue units remained on station until all passengers had deplaned. At 2130 h, ITÄ P3 and VSL4 decided that the situation had ended.

1.2.6 Police Department Actions

The police patrol photographed the airplane and visible tire damage. The patrol did not breath-test the flight crew.

1.2.7 Post-Occurrence Actions

The crew conducted a defuzing[8] session on board the airplane and continued defuzing later at the hotel. The flight crew was removed from operational flying for two days.

The air traffic controller filed a NOTAM[9] on the closure of the runway from 2050 to 2200 h. Another controller assigned for the night shift arrived at 2045 h and occupied the workstation thereby relieving the day shift controllers of operational control responsibility. The event did not significantly increase the workload of the night shift controller. After the shift change, the day shift controllers stayed in the ATC facility for approximately 30 min, discussing the

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8 Defuzing is a sit-down held immediately after a traumatic situation has taken place, aimed at stabilizing the situation. Its leader does not need to be a trained psychologist.

9 NOTAMs (notices to airmen) are advisories distributed by means of telecommunication that contain information concerning the establishment, conditions or change in any aeronautical facility, service, procedure or hazard, the timely knowledge of which is essential to personnel concerned with flight operations.

occurrence with the night shift controller. After the runway was rendered trafficable, flight AY217 departed at 2232 h.

The controllers were given CISM[10] support as per their employer's standing procedures. The controller filed a deviation and occurrence report[11] on the day following the event.

The aerodrome maintenance supervisor (LENTO P3) directed maintenance personnel to inspect the runway and document the event. LENTO P3 also directed personnel to conduct friction measurement and obtain photographs requested by the SIAF. Friction measurement and a runway inspection were conducted after approximately 25 min from the occurrence. The measured friction coefficients were 22, 20, and 22. It is likely that the amount of snowfall on the runway had by that time exceeded the validity range of the friction measuring device for the type of deposit.

Since the intensity of snowfall was growing, maintenance decided, at approximately 2155 h, to activate the Nopsa procedure[12]. Therefore, the runway conditions did not essentially differ from the values given in the SNOWTAM issued at 2003 h. The next SNOWTAM was scheduled for issue the following morning at 0531 h. This time was decided based on known traffic.

Finavia's operational instructions for aerodrome maintenance in incidents and accidents contain detailed guidance for maintenance personnel after a serious aviation incident and include the SIAF's guidelines for actions to be carried out after an aircraft accident or a serious incident. The document is described in more detail in paragraph 2.6.3.

On-duty maintenance personnel were interviewed and asked how they felt about the occurrence. They subsequently had a peer discussion on the event and stated that it was not sufficiently traumatic to deserve a defuzing session. Maintenance filed a deviation and occurrence report on the day following the event.

1.3 Consequences

The occurrence did not result in injuries. The mainwheel tires of the airplane exhibited wear due to wheel locking and hydroplaning and were rendered unserviceable. They also sustained damage by impact with the runway edge lights. The airplane remained at Turku for five days for damage assessment, inspections, and component replacement and departed on October 30, 2018. Indirect costs were incurred due to the airplane's removal from revenue service and because some components had to be replaced with leased spares during inspection and investigation. Five runway edge lights were broken and had to be replaced.

Since the single runway 08/26 was closed to air traffic by a NOTAM from 2050 to 2200 h the departure of a scheduled flight to Maarianhamina was delayed by over 2 hours.

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10 CISM (critical incident stress management) is a systematic post-crisis process used to help individuals who are experiencing a normal reaction resulting from an abnormal event. Its purpose is to alleviate the reactions of employees or other affected persons, restore the normal situation as soon as possible, and support return to their daily routine.

11 A standard-format report created after any deviation or anomaly

12 A national procedure that is activated when rapid and significant degradation of runway friction is occurring or is expected to occur.

2 BACKGROUND INFORMATION

2.1 Environment

2.1.1 Turku Aerodrome

Turku aerodrome (EFTU) is located eight kilometers north of downtown Turku. It has a single 2,500 m runway designated 08/26. In 2016, Turku airport handled 324,077 passengers and 8,012 t of cargo, which makes it the fourth and second busiest airport in Finland in terms of passenger and cargo traffic, respectively. The aerodrome is operational 24 h a day.

Movements include scheduled passenger, charter, and cargo services. The aerodrome is the base of Turku Air Patrol Flight of the Border Guard's Air Patrol Squadron and a FinnHEMS emergency medical services helicopter.

The aerodrome's winter maintenance category is II. Finavia's winter maintenance categories are described in paragraph 2.6.3.

Figure 6. Turku aerodrome (EFTU) (Photo: Orthophoto ©National Land Survey of Finland 6/2018)

2.1.2 CRJ900 Airplane and Systems Relevant to Occurrence

The Bombardier CRJ900 is a 90-seat medium-range airliner powered by two General Electric CF34-8C1 turbofan engines. Its maximum takeoff weight and maximum permitted landing weight are 37,995 and 34,065 kg, respectively. At this weight, the airplane's threshold crossing speed (V_{ref}) is 141 kt.

Figure 7. Bombardier CRJ900 (EI-FPD) (Photo: Police)

The thrust reverser system uses a set of blocker doors and cascade vanes to redirect engine thrust forward at an angle, thus creating a braking force. Reverse thrust is used during landing roll and in a rejected takeoff. Reverser control is independent for each engine.

The reversers are armed during approach and deployed after touchdown using reverse thrust levers mounted on the engine thrust levers. The blocker doors are hydraulically operated. A full authority digital engine control (FADEC) system enables hydraulic door operation after wheel speed has exceeded 20 kt or a landing gear weight-on-wheels (WOW) logic senses an aircraft-on-ground condition[13]. If the logic senses an airborne condition and the reversers are deployed, FADEC commands the engines to idle and triggers a FADEC FAULT message. Thrust cannot then be increased until both main landing gear WOW sensors record an aircraft-on-ground condition and the reversers have been selected stowed.

The anti-skid system improves airplane controllability and enhances braking effectiveness, particularly on a slippery runway. If a wheel is about to lock during braking, the system reduces hydraulic pressure applied to the respective brake unit. The system controls each of the four mainwheel brakes separately. The system is enabled on ground after it has been armed by operating a cockpit switch and the wheel speed is over 10 kt. When speed reduces to less than 10 kt, anti-skid protection is disabled and provides no locked wheel protection.

A touchdown protection logic in the anti-skid system guards against wheel locking on touchdown by preventing a gain in brake pressure for 5 s after a WOW signal records “ground” or until the wheel speed exceeds 35 kt. The logic monitors the status of each mainwheel separately. If the wheels do not rotate or spin up to the required 35 kt speed, the brakes will remain released for 5 s after a WOW signal has recorded “ground.” Thereafter, the logic will not restrict brake pressure since it interprets that the airplane is on the ground and traveling at a sufficiently slow speed.

The anti-skid system also indicates a condition wherein the rotational speed of one wheel is less than that of the other wheels by a predetermined amount when the airplane is on the ground, and a condition where a wheel continues spinning after landing gear retraction on takeoff. Additionally, the system, even though selected off, provides wheel speed information to other airplane systems.

2.2 Conditions

2.2.1 Weather Changes at Turku Aerodrome on Evening of October 25, 2017

A SPECIAL[14] at 1800 h indicated, among other information, that the wind was from 120° at 12 kt, variable between 7 and 22 kt. Visibility at runway 08 threshold was 7 km and 6 km at the runway end. Light sleet was falling, and clouds were broken at 1,400 ft and overcast at 2,300 ft.

A SPECIAL at 1845 h showed that the wind direction and speed were almost unchanged, but visibility at runway 08 threshold was 6 km and 3,900 m at the runway end. Light sleet had changed into light snowfall. The cloud base had lowered markedly, and was broken at 700 ft and overcast at 1,200 ft.

A SPECIAL at 1905 h reported the wind direction unchanged, but wind speed had picked up slightly. Visibility at runway 08 threshold was 4,200 m and 2,200 m at the runway end. Light

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[13] A weight-on-wheels signal indicates that a landing gear unit supports an amount of weight that is sufficient for the logic to interpret an aircraft-on-ground condition.

[14] SPECIAL is an aviation weather report on significantly changing weather conditions.

snow and 600 ft overcast were reported. A further special, issued 10 min later, reported that visibility at runway 08 threshold was 4,000 m and 1,900 m at the runway end. Snowfall had increased to moderate, and clouds were overcast at 500 ft. During the next hour, snowfall varied between light and moderate, while wind direction and speed and cloud base remained practically unchanged. Moderate snowfall was present at the time of the occurrence and continued for a considerable time afterwards. The subsequent SPECIAL messages showed almost no change in weather conditions.

Table 2. Essential weather changes, runway 26

SPECIAL at	Visibility	Wind (°/kt)	Precipitation	Clouds	Temperature
1800	6,000 m	120/15	Sleet	Broken 1,400 ft, overcast 1,200 ft	2 °C
1845	3,900 m	120/14	Light snow	Broken 700 ft, overcast 1,200 ft	1 °C
1905	2,200 m	130/17	Light snow	Overcast 600 ft	1 °C
1915	1,900 m	120/18	Moderate snow	Overcast 500 ft	0 °C
1945	2,100 m	120/18	Light snow	Overcast 500 ft	0 °C
2025	1,700 m	120/16	Moderate snow	Overcast 500 ft	0 °C

SPECIAL EFTU 251725Z WIND RWY 08 TDZ 120/15KT END 120/16KT VIS RWY 08 TDZ 2300M END 1700M MOD SN CLD OVC 500FT T00 DPMS00 QNH 1008HPA QFE 1002HPA

A SNOWTAM at 1934 h reported 1 mm of slush over all parts of runway 08 and estimated runway friction good. The conditions on the taxiways and apron were similar.

The next SNOWTAM at 2003 h reported 2 mm of slush over all parts of runway 08 and estimated runway friction medium. This SNOWTAM was in effect during the occurrence.

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A) EFTU
B) 10251702
C) 08
F) 6/6/6
G) 2/2/2
H) 3/3/3
T) RWY CONTAMINATION 1OO PER CENT OPR SIGNIFICANT CONT F) 6 G) 2 H)3/3/3
ALL TWY F) 56 H) 2 ALL APN F) 56 H) 2)

2.2.2 Hydroplaning

An aircraft may experience hydroplaning if a sufficient amount of water, slush, or wet snow is present on the runway or if a wheel locks during braking on a wet runway. The three types of airplane hydroplaning are *viscous hydroplaning, dynamic hydroplaning,* and *reverted rubber hydroplaning*. Viscous hydroplaning and dynamic hydroplaning occur in the footprint area where a rotating tire is in contact with the runway. They usually occur simultaneously at different points of the footprint. Before hydroplaning develops over the entire footprint area, part of the footprint area remains in contact with the runway and causes most of the friction. Reverted rubber hydroplaning occurs during prolonged wheel locking when friction induced heat changes water that is entrapped beneath the tire into steam.

Viscous hydroplaning arises on a wet runway. The friction between the tire and the runway is reduced but not enough to impede wheel rotation. The tire rolls in contact with the high points of the runway macrotexture, but water is entrapped between the tire and pits that exist due to surface roughness. Some of this water is expelled, the amount of expelled water depending on its viscosity. Contaminants and ice crystals may increase viscosity, and therefore the squeezing-out of the water from the footprint area will increase resistance.

Dynamic hydroplaning develops from viscous hydroplaning and occurs at higher speeds. At sufficiently high speeds, water entrapped between the tire and the runway will not expel owing to its inertia. Hydrostatic pressure thus created between the tire and the runway tends to lift the tire upward. If the force resulting from hydrodynamic pressure increases sufficiently, the tire will rise completely off the runway and ride on a cushion of water. At this point dynamic hydroplaning has developed over the entire footprint, and the friction between the tire and the runway is extremely low. In this condition, the tire is unable to transmit forces; its rotation slows down and may even stop completely as hydrodynamic pressure builds up at the forward edge of the footprint and creates a force that resists rotation. It has been found that since a non-rotating tire has a lower hydroplaning speed, it remains in a hydroplaning condition longer than a rotating tire. Hydroplaning may occur at fairly low speeds over smooth surfaces such as runway sections coated with rubber deposits. The risk of hydroplaning can be alleviated by runway grooving. On a grooved area water collects in the grooves and enables a higher level of contact between the tire and the runway.

Reverted rubber (steam) hydroplaning occurs when a locked tire skids along the runway, and heat changes water[15] that is entrapped under the tire into steam. The onset of this type of hydroplaning may be abrupt, for example if the wheel locks during braking, or it may follow dynamic hydroplaning after the speed has reduced and the locked tire has regained runway contact. Friction generated by the locked tire melts the rubber and reverts it to its original uncured state. This creates a seal around the edges of the footprint which traps water between the tire and the runway. Water heats up and changes into steam, and as a result the tire rises and starts to slide on a film of water and steam. In this condition the locked wheel is practically unable to transmit braking forces or lateral forces. It sustains wear, and a burn area appears on the tread. Only a thin film of water on the runway is required to facilitate reverted rubber hydroplaning. Reverted rubber hydroplaning may persist down to very low groundspeeds, even as low as below 20 kt, and is the most troublesome form of hydroplaning from an aircraft controllability point of view.

If groundspeed is sufficiently high and the runway is coated with water or slush, an aircraft may enter a hydroplaning condition immediately on touchdown, in which case wheel rotation may be completely impeded. Landings at higher-than-normal groundspeeds, caused by tailwind or any other reason, will increase the risk of hydroplaning. In addition to the thickness of the water layer, tire pressure has an effect on the dynamic hydroplaning speed.

The majority of current knowledge on the hydroplaning characteristics of aircraft tires is based on research conducted by the National Aeronautics and Space Administration (NASA) of the United States in the 1960s. The studies established, for the hydroplaning speed of tires, an equation in which the sole variable is tire pressure. The formula

$$v_{hydro} = 9 \times \sqrt{tire\ pressure\ (psi)}$$

[15] Snow and ice will also melt and change into steam.

was derived from the equation of hydrodynamic lift force to produce an approximation of the minimum hydroplaning speed of a tire in knots. Subsequent tests have shown that the equation yields excessively high hydroplaning speeds for modern aircraft tires, which may enter a hydroplaning condition at speeds of tens of percent lower than those derived from the foregoing equation. A study conducted in 2001[16] shows that if the factor 9 in Horne's formula is replaced by factor 6.4 or 6, the result correlates better with bias-ply tires and type-H tires, respectively. Tire size and load also have some effect on the results. In any case, the equation yields only approximations for the minimum hydroplaning speed. If a speed derived from the equation is exceeded significantly, the aircraft will likely hydroplane if the runway is coated with a sufficient thickness of water or slush.

2.3 Personnel, Organizations, and Safety Management

2.3.1 Airline

The occurrence flight was operated by CityJet, headquartered in Dublin, Ireland. The route was previously served by the Finnish company Blue1, which CityJet bought from SAS in October 2015. In conjunction with the purchase, CityJet signed a contract for 8 + 6 airplanes for three years with an option to extend the agreement. The contract is a wet lease agreement in which CityJet leases to SAS airplanes, crews, technical staff, maintenance services, and full insurance protection. The arrangement is widely used in the airline industry. Under a wet lease contract, the lessee (in this case SAS) uses its own flight numbers (in this case SK4236). The opposite is a dry lease contract, which covers only an airplane and no supporting services.

The route of the flight was operated by Air Botnia in 1988–2003. SAS acquired Air Botnia in 1998 and rebranded it Blue1 in 2003. Blue1 operated mainly feeder services for SAS and domestic routes in Finland and also offered seasonal services to Central and Southern European destinations. In 2011 it cut down its network to include only flights within Scandinavia until acquired by CityJet in 2015.

2.4 Rescue Services and Preparedness

2.4.1 Southwestern Finland Rescue Department

The Southwestern Finland Rescue Department is prepared for serious incidents and aircraft accidents at Turku aerodrome as part of its contingency planning. Preparedness includes participation in full-scale emergency exercises that are arranged every two years. The aerodrome maintains an aerodrome emergency plan together with Finavia. Response plans also include procedures for a major aircraft accident and the handling of communications over the nationwide public safety network. Operational control within the department is executed by five on-duty fire officers positioned in the department's area of responsibility and one officer-in-charge. The driving times to the aerodrome from Kärsämäki regional fire station and Turku central fire station are approximately 5 and 15 minutes, respectively. The department also conducts scheduled inspections at the aerodrome's buildings.

2.4.2 Paramedic Operations

Paramedic operations in Southwestern Finland are under the control and oversight of four on-duty paramedic field supervisors (L4) of the Southwestern Finland Health Care District. One of them is located in Turku, while three area field supervisors are positioned at various

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16 Van Es GWH. (2001) Hydroplaning of Modern Aircraft Tires. National Aerospace Laboratory NLR. NLR-TP-2001-242

locations within the district's area. A situation center has operational control on paramedic operations and maintains a situation picture of paramedic services.

The on-duty field supervisors execute on-scene command and control within their assigned areas. They oversee operations and compliance with the currently effective paramedic service standard decision. The field supervisor at Turku may transfer the responsibility for the oversight of Turku area to another area field supervisor if the operational situation so requires. The area field supervisors may on a mutual agreement transfer the oversight responsibility to the situation center.

2.4.3 Aeronautical Search and Rescue Coordination Center

Pursuant to Annex 12 to the Convention on International Civil Aviation of ICAO[17], Finland offers aeronautical search and rescue services within its territory. At the operational level, the services are provided by the Aeronautical Search and Rescue Coordination Center (ARCC) of Air Navigation Services (ANS) Finland. The ARCC maintains round-the-clock readiness to initiate actions to locate a missing aircraft in cooperation with other authorities. In the event of an accident or a serious incident, the ARCC will coordinate search and rescue and provide air search until the aircraft is located.

The ARCC trains and exercises its staff and participates annually in joint exercises with other authorities.

The Finnish Transport Safety Agency (Trafi) regulates aeronautical search and rescue pursuant to section 121 of the Aviation Act and oversees compliance with the regulations.

2.4.4 Aerodrome Rescue and Fire Fighting Services

Turku aerodrome is maintained by Finavia. Aviation regulations require that aerodromes have sufficient rescue capabilities and the ability to deal with aircraft accidents. The number of personnel on standby and the type and number of rescue units are determined in terms of aerodrome rescue and firefighting (ARFF) categories based on the largest aircraft type that operates from an aerodrome at a given time. Turku aerodrome is in category 7. The ARFF categories and ARFF preparedness levels are published in aviation regulation AGA M3-11.

The aerodrome maintenance supervisor (LENTO P3) directs aerodrome rescue units in emergencies and during exercises. The ARFF at Turku aerodrome will respond to aircraft accidents and serious incidents that occur within the aerodrome area. The minimum day and night shift operational manning is 1 + 2 and 1 + 1 persons, respectively. Maintenance has two rescue units on 24/7 standby at a single fire station, and they are required to roll within 3 min of an alarm. ARFF personnel also attend to maintenance and other duties as per their job descriptions. ARFF is tasked to function as a part of the integrated rescue organization.

Turku aerodrome is responsible for rescue actions and preparedness which, pursuant to the Rescue Act (379/2011), are not the responsibility of regional rescue services. In the event of an aircraft accident at the aerodrome, LENTO P3 directs ARFF until a rescue authority is notified of the accident and assumes operational control.

According to aviation regulations, an ATC facility must have an audible and visual alarm system. An alarm will also be issued on the ARFF radio frequency and via the nationwide public safety telephone network. An ERC will be notified of an emergency by telephone.

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17 ICAO = International Civil Aviation Organization

Regular emergency exercises are an integral part of an aerodrome emergency plan and enable its testing in practise. Aviation regulations divide these exercises into two categories. Full-scale exercises are held every two years in cooperation with rescue services and other authorities to rehearse all ARFF functions and multiauthority cooperation. Partial exercises are arranged at the aerodromes. The previous full-scale exercise at Turku was on September 12, 2017, while the previous partial exercise took place on November 4, 2016.

2.5 Recordings

2.5.1 Flight Data Recorder and Engine Control System Data

The occurrence airplane's FDR[18] yielded essential data for the investigation. The data was also used to create a video animation of the occurrence.

The data indicates that the airplane was traveling at 151 kt groundspeed and 148 kt airspeed at touchdown. Consequently, the tailwind component at touchdown was 3 kt.

The data shows the status of signals provided by weight-on-wheels (WOW) sensors that are mounted on the main landing gear oleo struts to monitor strut extension and thereby determine whether the wheels are carrying load and thence in contact with the ground. The left and right main gear touched down almost simultaneously at 0.25 s interval. Approximately 1 s later, load on the right main gear lightened sufficiently for the logic to record "air." This condition lasted for 0.25 s (Figure 8, A). The tire did not necessarily rise off the runway, but the oleo extension (0.47 g) that followed the firm (1.95 g) landing may have reduced the load on the tire to such an extent that "air" was recorded. Nose gear touchdown occurred at the same time.

At the same moment, the thrust levers were moved to the reverse thrust position. This triggered a master caution (Figure 8, B) since reverse thrust is inhibited unless the WOW logic records "ground."

Manual brake pedal application (Figure 8, C) was recorded simultaneously with the master caution. Brake application is not shown in FDR graphs until brake pressure increases to 500–800 psi so light braking and even many normal brake applications remain unregistered. However, pressure in the brake units did not increase despite brake application (Figure 8, D) due to the operation of the touchdown protection logic that is designed to guard against wheel locking on touchdown. The logic prevents pressure increase in the brake units until wheel speed is over 35 kt or the WOW sensors record "ground" for more than 5 s. Brake pressure started to rise (Figure 8, D) after approximately 5 s from the first "ground" signal from the WOW sensors.

[18] FDR = flight data recorder

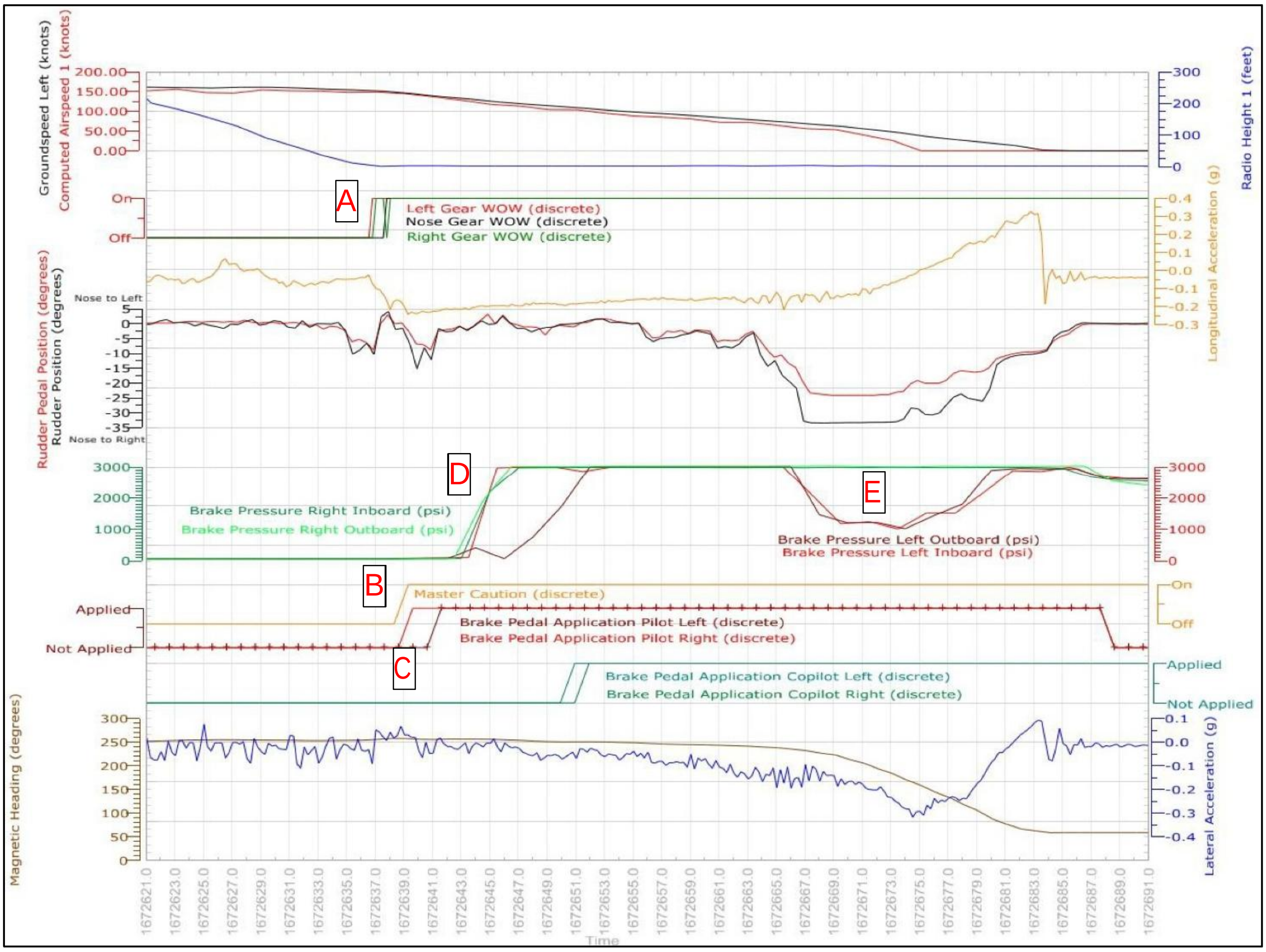

Figure 8. Flight data recorder parameters (Photo: FDR time history trace / Bombardier, overlays SIAF)

The FDR does not capture wheel speed information. A sequence of FADEC snapshots (Figure 9) shows that the maximum wheel speed was less than 3.5 kt when the master caution was displayed. By this time, the wheels had been in ground contact for approximately 2 s but were barely rotating. The FADEC captured data only during the appearance of the master caution.

Signal Name	SnapShot#1 Value	SnapShot#2 Value	SnapShot#3 Value	SnapShot#4 Value	SnapShot#5 Value	SnapShot#6 Value
WOW	TRUE	TRUE	FALSE	TRUE	FALSE	FALSE
WHSPD	+1.2187500	+1.1250000	+1.1250000	+1.2812500	+1.4062500	+3.4062500

Figure 9. Mainwheel speed (WHSPD) and weight on wheels signal (WOW) values when the master caution was displayed. The snapshots were taken at 0.16 s intervals so the approximate duration of the sequence is 0.96 s. (Photo: General Electric)

The anti-skid system controls each mainwheel independently to prevent wheel locking during braking. The system is enabled when the wheel speed is over 10 kt. If the wheel speed is below 10 kt, the system will not modulate brake pressure. The brake pressure graphs show that the brake pressure in all wheels except left outboard increased to the maximum value (3,000 psi) within approximately 4 s. Left outboard wheel pressure initially increased by slightly more than 400 psi and then dropped to approximately 70 psi (Figure 8, D) before increasing to maximum during 6 s, thus becoming consistent with the brake pressure at the other wheels. It is possible that the left outboard wheel momentarily spun up to more than

10 kt and the anti-skid system reduced brake pressure during braking to prevent wheel locking. The wheel speed did not subsequently exceed 10 kt and the system therefore applied maximum brake pressure. Maximum pressure was maintained in all brake units during the landing roll with the exception of the moment when the hydraulic pressure in both left landing gear brakes dropped to approximately 1,200 psi (Figure 8, E) and then increased again to the maximum. Even on a dry runway, the pressure of 1,200 psi will be sufficient to maintain a locked wheel condition. Examination found no anomalies in the operation of the anti-skid system component that modulates brake pressure. The foregoing pressure drop was consistent with the lightening of pressure on the left brake pedal.

2.5.2 Cockpit Voice Recorder

A total of 2 h of data was available. The recording began 24 min 26 s before landing at Turku. CVR [19] data supported information obtained from radio communications between the flight crew and ATC.

2.5.3 Radio Communications

Recorded radio communications contained essential information of discussions between ATC and the flight crew and between ATC and aerodrome maintenance. The information conveys a picture of the onset of the occurrence and subsequent actions.

2.5.4 Emergency Response Center Recordings

The study of the recorded emergency call indicated that the ERC dispatcher received situational information via the open telephone line while the controller was communicating with the aerodrome maintenance and the flight crew. Information on the rescue units alerted to the scene and on their arrival times was obtained from the ERC's operational logs and its Pronto assignment database.

2.6 Rules, Regulations, Procedures and Other Documentation

2.6.1 Finavia Documentation

The applicable emergency plans detail actions by aerodrome staff in the event of an aircraft accident at Turku aerodrome or in its immediate vicinity. The plans are prepared together with the Southwestern Finland Rescue Department.

2.6.2 CityJet Documentation

Paragraph 2.4.9 of company Organisation Management Manual Part B (OM-B) contains the following sequence of actions on landing: 1) (Both) main gear touchdown, 2) Nose gear touchdown, 3) Check spoilers deployed, 4) Apply brakes, and 5) deploy reverse thrust.

Paragraph 2.5.7 of OM-B contains the following guidance on crosswind landings on a contaminated runway:

"A slippery runway and a crosswind are obviously a bad combination. In crosswind conditions, the crosswind crab angle should be maintained for as long as possible until prior to touchdown. Aim for the centreline or slightly on the upwind side and avoid touching down on the downwind side of the runway. This technique will minimize the possibility of the airplane weathervaning into wind after touchdown, and drifting toward the downwind side of the runway. If the airplane starts to skid or drift gradually, it may be necessary to move the thrust levers out of reverse

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19 CVR = cockpit voice recorder

thrust and to go to forward idle thrust to recover the centreline. It may also be necessary to reduce the brake pressure to regain control and re-establish alignment with the centreline."

Paragraph 2.5.8 of OM-B contains the following guidance on reverse thrust operation:

"...The use of reverse thrust during crosswind conditions may aggravate directional control of the aircraft. If the airplane is allowed to weathervane into the wind, the reverse thrust side component will add to the crosswind component, drifting the airplane toward the downwind side of the runway at a faster rate than normal. To correct the situation, it will be necessary to reduce the reverse thrust to reverse idle and release the brakes. In extreme conditions, it may even be necessary to move the thrust levers out of reverse thrust and go to forward idle thrust. Use rudder steering and differential braking as required to prevent over-correcting past the runway centreline. When re-established on the runway centreline, reapply steady brakes and reverse thrust as required to stop the airplane."

In September 2015, the company issued Supplement 2A "Operation on Contaminated Runways" to its Flight Crew Operating Manual (FCOM) that gives information on hydroplaning speeds.

Initiation of hydroplaning for the Regional Jet is calculated as follows:

Contaminant	Tire Pressure (psi)	Hydroplaning Ground Speed (KTS)
Standing water (δ = 1.00)	MAIN: 166	116
	NOSE: 149	110
SLUSH (δ = 0.85	MAIN: 166	116
	NOSE: 149	110
WET SNOW (δ = 0.50)	MAIN: 166	116
	NOSE: 149	110
DRY SNOW (δ = 0.20)	MAIN: 166	N/A
	NOSE: 149	

NOTE

1. Tire pressure are determined with the airplane on the ground.
2. δ = specific gravity of contaminant.

Figure 10. Hydroplaning speeds for contaminated runways (Photo: CityJet FCOM)

The company training manual (Operations Manual Part D, revised on September 6, 2017) has a section on winter operations.

SECTION	CONTENT	HOURS
1	• De-icing and Anti-Icing Materials and Procedures • Hold Over Time • CityJet RJ85/CRJ-900/SSJ-100 Procedures	1.0
Examination		1.0

Figure 11. CityJet winter operations training

The course covers company procedures for winter operations and its duration is 1 h.

In October 2016, the company issued to its flight crews a mandatory read bulletin titled "Winterization 2016/2017." The bulletin stated that flight crew members had to attend winter operations training by the end of October and recommended that they also do Bombardier's network training courses for winter operations. The bulletin has a section titled "Landing on Contaminated (and Slippery) Runways" that contains, among other information, the following guidance: "Consider diversion to an uncontaminated runway when a failure affecting landing performance is present," and "Monitor late wind changes and GA if unexpected tailwind (planning to land on contaminated runway with tailwind should be avoided)."

2.6.3 Authorities' Procedures and Regulations

Finavia's operational instructions for aerodrome maintenance in incidents and accidents state that safety reporting should be in accordance with Finavia's safety management system (SMS) manual appendix C (deviation and occurrence reporting).

Paragraph 1.2 of the foregoing instructions contains the following: *If it can be assumed that runway conditions have contributed to a serious incident the focus of post-incident actions is to prevent further damage and verify the conditions at the time of the incident. In winter this means that a runway inspection should be conducted immediately, and the present runway friction and other circumstances at the scene of the incident should be determined. Photographic or video imagery of the circumstances at the scene or of any observable traces will assist a possible investigation.*

Paragraph 1.3 of the foregoing instructions contains *SIAF's instructions for post-accident actions before and after an investigation team's arrival and also states that a friction measurement is to be conducted immediately. A standard runway inspection should also be performed to determine the conditions along the runway.*

Finavia's winter maintenance manual divides Finland's aerodromes into four winter maintenance categories designated IA, IB, II, and III. The only category IA aerodrome ("category II summer surface") is Helsinki-Vantaa. Rovaniemi and Oulu are in category IB ("category II summer surface"), while Turku is in category II ("summer surface"). The objective of aerodrome maintenance at Turku is to keep the active runway free of snow and ice at least over the minimum width of the cleared area[20]. The width is determined on a case-by-case basis depending on the requirements imposed by the departing or arriving airplane type. The friction and smoothness of other areas will be maintained at an adequate level, and these areas may be snow-covered. The areas forward of the ILS installation will be maintained cleared. Sanding is allowed unless it is restricted by agreements or regulations. The SNOWTAM validity period at Turku aerodrome is restricted to 6 h.

Finavia's aerodromes use Skiddometer BV11 friction measurement devices. The device's validity threshold for slush is ≤ 3 mm deposit thickness. (Source: Finavia's winter maintenance manual)

Actions to increase friction shall be started when the runway friction coefficient is below 0.40. Reported friction values always represent estimated runway friction. An adequate number of sample measurements is made to support the estimate and obtain a reliable picture of the prevailing conditions over the entire runway. The friction level must not be estimated to be higher than the average values obtained with the measuring device. (Source: Finavia's winter maintenance manual)

20 The minimum runway width that is intended to be cleared under exceptional circumstances

Table 3. Friction table in Finavia’s winter maintenance manual

Measured coefficient	Estimated surface friction	Code
0.40 ≥	Good	5
0.36–0.39	Medium to good	4
0.30–0.35	Medium	3
0.26–0.29	Medium to poor	2
0.15–0.25	Poor	1

Associated with the manual “Aerodrome Maintenance Procedures for Abnormal Situations,” Finavia issued in 2016 a training syllabus for aerodrome maintenance that defines the competencies required of maintenance personnel. A new employee first attends familiarization and occupational guidance at a local aerodrome and then undergoes Avia College's basic training for aerodrome maintenance. Most of the learning takes place at the local airport under the supervision of experienced colleagues.

To be eligible for maintenance supervisor training, an individual has to complete Finavia’s basic and recurrent training in aerodrome maintenance or demonstrate equivalent knowledge. It is recommended that a supervisor's recurrent training is attended within 5 years of basic training.

To qualify as a runway inspector, an individual needs to have, among other requirements, two seasons of winter experience of working in the movement area or equivalent experience, and passed Finavia’s local maintenance familiarization training to the required extent. Runway condition assessment is based on knowledge – that builds with experience – and on familiarity with the local conditions. Even though a number of types of equipment have been tested for the assessment of deposit thickness, such as the depth of a slush layer, visual evaluation remains the best method.

Finavia's alerting service manual details the contents of an alarm issued by an aerodrome ATS[21] unit as follows:

- Notify of the emergency via the public address (PA) system and/or activate the alarm system. This will initiate response by the aerodrome ARFF.
- Explain the situation and the cause of the alarm via the PA system, on the ground control frequency, or by any other suitable means.
- Give the nature of the emergency (aircraft accident or accident hazard).
- Give the type (and operator) of the aircraft.
- Give estimated landing time and runway.
- On the ground control frequency, give fill-ins (POB, fuel quantity, dangerous cargo and any other essential information). LENTO P3 will relay this information to arriving rescue units.
- Note any additional local instructions.

According to the manual, a controller should relay additional information to the ERC only when LENTO P3 is not the incident commander. In other cases, LENTO P3 will relay additional information to arriving rescue units. In events at and in the vicinity of an aerodrome, LENTO P3 will remain the incident commander until the on-duty fire officer assumes the tasks of the incident commander.

2.6.4 Rescue Department and Police Procedures

Rescue department procedures. The aerodrome is within the city limits of Turku. Pursuant to the Rescue Act, the Southwestern Finland Rescue Department exercises overall command and control of rescue operations and is responsible for command and control in aircraft accidents that occur at the aerodrome or in its vicinity. The general capability of the rescue service in the region is adjusted to conform to a decision on the standard of service submitted and approved in accordance with the Rescue Act. The current decision is effective in 2017–2020. The procedures include an action plan for a major aircraft accident at the aerodrome which was approved for use on July 6, 2017. According to the plan, a rescue authority will exercise overall command and control, allocate the necessary resources, and issue appropriate orders.

Paramedic procedures. The Southwestern Finland Health Care District is responsible for urgent pre-hospital care within its area of responsibility. The Health Care Act (1326/2010) requires that a joint municipal authority responsible for special health care decides on the standard of pre-hospital medical care within its area. A decision effective in 2015–2017 governed the district's operations at the time of the occurrence. The district uses several service providers for pre-hospital care. These include in-house facilities, joint facilities with the regional rescue department, and outsourced services.

The emergency response center risk assessment model[22] divides aircraft accidents into three alert categories, which are minor, medium, and major. Paramedic units are always alerted regardless of the category of the accident provided the criteria laid down in the risk assessment model are met.

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21 ATS = air traffic services

22 A computer-based risk assessment model that combines the risk assessment procedures of several authorities

A directive issued by the National Police Board[23] details police department actions at aircraft accident scenes. These include the verification of the flight crew's condition by breathalyzing and toxic substance control.

2.7 Other Research

2.7.1 CRJ900 Maximum Landing Weight Calculations

The aircraft's landing performance is determined as follows:

Table 4. Chart for limiting landing weight (Source: CityJet CRJ Performance Handbook)

TURKU	-EFTU					
FLAPS 45 - ALL COMPONENTS OPERATIVE - WET RWY - NO WIND/STD PRESS						
PACKS ON		MAXIMUM LANDING WEIGHT (/100) / LIMIT CODE / FLAP SETTING				
OAT °C	N1%	08 2500m	26 2500m			
20	90.0	402A45	402A45			
15	90.0	402A45	402A45			
10	90.0	402A45	402A45			
5	90.0	402A45	402A45			
0	90.0	402A45	402A45			
-5	90.0	402A45	402A45			
-10	90.0	402A45	402A45			
-15	80.0	402A45	402A45			

At 0 °C outside air temperature (OAT), the code for runway 26 at Turku is 402A45, in which:

- 402 is the maximum performance limited landing weight / 100, i.e., 40,200 kg
- A is the performance limiting factor (maximum AFM chart weight)
- 45 is the flap setting used for the calculation.

Reported friction was medium, and the deposit was 2 mm of slush. The table shown below is used to obtain the braking action (BA) category, which is medium/poor.

Table 5. Table for interpreting friction level and runway conditions (Source: CityJet OM-B)

Performance table BA category	Use for reported braking actions:	Use for reported contaminant types:
GOOD/MED	Good (FC 0.40 and above)	
GOOD/MED	Medium - Good (FC 0.39 to 0.36)	Compacted snow
MED/POOR	Medium (FC 0.35 to 0.30)	Dry snow (>25 mm), Wet snow (> 6 mm)
MED/POOR	Medium - Poor (FC 0.29 to 0.26)	Standing water (> 3 mm), Slush (> 3 mm)
POOR	Poor (FC 0.25 to 0.16)	Ice

The correction for the prevailing conditions is made using the table shown below.

23 Procedures for aircraft accident investigation, December 13, 2013

Table 6. Correction table for wind effects (Source: CityJet CRJ Performance Handbook)

	LANDING FIELD LENGTH LIMIT WEIGHT (/100)	
	08 2500m	26 2500m
*** FLAPS 45 ***		
Dry Runway	402	402
TW/HW per kt	+0/ +0	+0/ +0
1Pair Splrs Inop	402	402
TW/HW per kt	-5/ +0	-5/ +0
Anti-Skid Inop	257	257
TW/HW per kt	---/ +3	---/ +3
Wet Runway	402	402
TW/HW per kt	-4/ +0	-4/ +0
1Pair Splrs Inop	383	383
TW/HW per kt	-8/ +2	-8/ +2
BA GOOD/MED	402	402
TW/HW per kt	-4/ +0	-4/ +0
1 T/R Inop	402	402
TW/HW per kt	-4/ +0	-4/ +0
BA MED/POOR	402	402
TW/HW per kt	-8/ +0	-8/ +0
1 T/R Inop	372	372
TW/HW per kt	-8/ +3	-8/ +3
BA POOR	291	291
TW/HW per kt	-8/ +3	-8/ +3

Select BA MED/POOR in the table. Take tailwind (TW) into account by subtracting from the maximum performance limited landing weight 800 kg for every knot:

$$40200\ kg - 10\ kt * 800 \frac{kg}{kt} = 32200\ kg$$

2.7.2 Norwegian Investigation on Winter Operations and Friction Measurement

The Accident Investigation Board Norway (AIBN) conducted, in 2011, a theme investigation on aircraft winter operations[24]. Over a more than 10-year period, AIBN had received 30 reports of accidents and incidents related to operations on winter-contaminated[25] and slippery runways. Investigations into these occurrences found that the aircraft braking coefficient was not in accordance with the measured or estimated runway friction coefficients and revealed underlying factors related to meteorological conditions, friction measurement uncertainty, runway treatment, operational aspects, and regulatory conditions. An overarching finding was that operators considered measured values and estimates accurate with no regard to other meteorological factors.

Investigation into the 30 occurrences discovered several coinciding safety indicators, of which the following were listed in the report:

- dew point spread (difference between air temperature and dew point temperature) $\leq$ 3 K (Kelvin)
- wet or moist runway
- $\geq$ 10 kt crosswind combined with a slippery runway
- dew point spread $\leq$ 3 K combined with air temperature of $\geq$ -3 °C

24 https://www.aibn.no/Aviation/Reports/2011-10
25 Winter contamination means hoar frost, ice, slush, wet snow, dry snow, or ice.

- loose slush or wet or dry snow on top of compacted ice and snow
- dew point spread ≤ 3 K combined with ≥ 10 kt crosswind
- dew point spread ≤ 3 K combined with ≥ 10 kt crosswind and air temperature of ≥ -3 °C
- measured friction coefficient > 0.40 while the pilots found the actual braking coefficient poor at an air temperature of < -9 °C, dew point spread 2–4 K and > 10 kt crosswind

The report identifies the following most significant findings:

- The importance of humidity in the definition of snow types. The content of liquid water in snow is very temperature-dependent. Hence snow, and particularly newly fallen snow, has a relatively high content of liquid water which together with other contamination can make the runway very slippery, even in sub-zero temperatures. It was found that a dew point spread of ≤ 3 K was an indication of slipperiness. This usually indicates an air humidity of 80 % or more. An important issue is that the temperature at the runway surface may be lower than the value measured at 2 m height, and therefore the dew point spread may be ≤ 3 K at the surface. It should also be noted that the dew point spread changes by approximately 1 degree for every 10 degrees below zero; hence, the margin is reduced to 2 K at -10 °C and to 1 K at -20 °C.
- Validity ranges of friction measurement devices. The report states that friction measurement devices are approved for operation within the following validity ranges but does not mention whether the ranges always apply to asphalted surfaces or a contaminated surface such as ice or compacted snow. The referred deposits are:
  - dry snow ≤ 25 mm deep
  - dry compact snow irrespective of depth
  - dry ice irrespective of depth
  - slush ≤ 3 mm deep
  - wet snow ≤ 3 mm deep
  - wet ice.
- Friction measurement uncertainties. Research programs have shown that the tolerances of friction measurements are ± 0.1 for dry and ± 0.2 for wet contaminations, respectively. Yet the measured values are accepted as accurate. The AIBN has found that when the friction coefficient is measured on compacted snow or ice and the contaminant is wet or moist or the dew point spread is ≤ 3 K, aircraft braking action may be 0.05 (poor) while the measured friction coefficient can be 0.40 (good) or higher. This uncertainty seems to apply to all types of friction measurement devices.
- Crosswind conditions combined with slippery runways. AIBN has found that some airlines' use of crosswind tables was overly optimistic. It should be noted that the dew point and air temperature related factors affect also crosswind landings. Under such conditions, snow and ice particles can polish the ice and sand grains and cover them in a film of ice. These conditions may result in measured friction values of > 0.40, and are understood to constitute good winter conditions while aircraft braking action may be poor. It was found that snow and ice particles can change the properties of the surface beneath the aircraft's wheels, which may lead to serious misinterpretations of runway friction.
- Cornering friction during simultaneous braking and steering. Braking friction will be at the expense of cornering friction and is reduced by an increasing slip ratio. Cornering friction occurs when the aircraft turns, and during crosswind landings it is required to keep the aircraft tracking straight along the runway.

- Prepared runways with reduced widths. AIBN found in two investigations that operations had been permitted on runways with a prepared width of 30 m.
- Friction-improving measures. The ICAO Airport Services Manual gives a grain size for sanding, but otherwise international and national authorities have not issued any special requirements. Sanding methods include the use of warm sand and pre-wetted sand that bond with the contaminant. Sanding has little effect on slush and other loose contaminants since the sand is pushed away from the wheels together with the contamination. Chemicals can be used to prevent ice formation or to melt ice that can then be removed mechanically. One problem is that chemicals dissolved in water can freeze in low temperatures. Also, under certain conditions the solution can form a slippery film on the runway. Moreover, chemicals are detrimental to the environment and can accelerate runway wear and cause damage to aircraft.
- Use of wind data in landing calculations. AIBN found in five investigations that the landing calculations were based on ATC tower readings of instantaneous wind speeds (2 min readings or 3 s gust readings) instead of METAR (meteorological terminal air report) or ATIS (automatic terminal information service) data based on 10 min readings. It was also found that pilots are more concerned about the combination of friction and crosswind at the touchdown point than they are about the condition further down the runway where braking and cornering friction are more important. At the landing point the aircraft is controlled by the aerodynamic forces, while at 100 kt, at lower speeds the aircraft becomes a “ground vehicle” and its directional control and braking depend entirely on frictional forces. AIBN has found that runway excursions do not occur on the first third of the runway, but normally on the last third.
- Use of reverse thrust in landing calculations. This varies. The aircraft certification requirements are based on testing on a dry runway without the use of reverse thrust. The data is published in the AFM and used by the airlines to calculate landing distances and maximum weights. Airframers’ data is based on calculations using theoretical friction values for various types (such as ice, snow, and slush) of contamination and measured friction coefficients, or both. Investigations have discovered that the use of reverse thrust in landing calculations is at the airlines’ discretion. In practice, these calculations take into account the use of reverse thrust for jet aircraft, while for propeller aircraft reverse braking is not included in the calculations.

The AIBN issued seven safety recommendations, which are explained below.

- Winter operations do not enjoy the same safety margin as summer operations. AIBN recommends that Civil Aviation Authority (CAA) Norway carries out a risk assessment and considers introducing national limitations of winter operations to ensure an equivalent level of safety.
- Differences exist between various friction measuring devices, and different values can be obtained when they are used on the same surface. AIBN recommends that ICAO, Federal Aviation Administration (FAA) of the United States, and CAA Norway review and validate the permitted measuring ranges for the approved devices.
- ICAO’s SNOWTAM table shows measured friction values in hundredths (1/100) even though the figures should not be reported to more than tenths (1/10) due the uncertainty of friction measurement devices. Airlines use the table through their individual correlation tables or graphs, which further increases the uncertainty. AIBN recommends that ICAO, FAA, EASA, and CAA Norway review the SNOWTAM table to reduce the degree of friction uncertainty.

- Reverse thrust represents approximately 20 % of the total available braking force on landing on a slippery runway. AIBN recommends that ICAO, FAA, EASA, and CAA Norway consider whether reverse thrust should continue to be included in part or in whole in the calculation of the required landing distance on contaminated and slippery runways.
- The crosswind limit tables for operations from slippery runways differ from each other. AIBN recommends that ICAO, FAA, EASA, and CAA Norway evaluate the airlines' crosswind limits in relation to friction values and consider whether they should be subject to separate approval by authorities.
- EASA's default friction values for various contaminants are optimistic and do not take into account the temperature, dew point, and the depth of contamination, They are not in accordance with the the AIBN's findings. AIBN recommends that EASA considers a more conservative determination of friction values on various types and depths of contamination.
- The ICAO Airport Services Manual is outdated and not very appropriate as support for today's winter operations. The manual should describe in more detail the new types of friction measuring devices and their limitations, deicing requirements, and the characteristics and use of chemicals. The information on expected friction on different depths of contamination should also be updated. AIBN recommends that ICAO updates the Airport Services Manual on the basis of the results of investigations into runway excursions and research findings.

2.7.3 Federal Aviation Administration Safety Alert 2016

FAA oversees aerodrome safety in the United States. On August 15, 2016, it issued a safety alert titled "Runway Assessment and Condition Reporting, Effective October 1, 2016" bearing the identifier SAFO 16009[26]. The safety alert contains a matrix for runway condition assessment. In the matrix, a slush deposit of > 3 mm would result in medium to poor braking action. On the other hand, the foregoing AIBN recommendation would give braking action under the equivalent conditions as "poor."

[26] https://www.faa.gov/other_visit/aviation_industry/airline_operators/airline_safety/safo/all_safos/media/2016/SAFO16009.pdf

Table 7. Runway condition assessment matrix (Source: FAA)

Assessment Criteria		Control/Braking Assessment Criteria	
Runway Condition Description	**RwyCC**	**Deceleration or Directional Control Observation**	**Pilot Reported Braking Action**
• Dry	6	---	---
• Frost • Wet (Includes damp and 1/8 inch depth or less of water) ***1/8 inch (3mm) depth or less of:*** • Slush • Dry Snow • Wet Snow	5	Braking deceleration is normal for the wheel braking effort applied AND directional control is normal.	Good
-15ºC and Colder outside air temperature: • Compacted Snow	4	Braking deceleration OR directional control is between Good and Medium.	Good to Medium
• Slippery When Wet (wet runway) • Dry Snow or Wet Snow (any depth) over Compacted Snow ***Greater than 1/8 inch (3 mm) depth of:*** • Dry Snow • Wet Snow ***Warmer than -15ºC outside air temperature:*** • Compacted Snow	3	Braking deceleration is noticeably reduced for the wheel braking effort applied OR directional control is noticeably reduced.	Medium
Greater than 1/8 inch(3 mm) depth of: • Water • Slush	2	Braking deceleration OR directional control is between Medium and Poor.	Medium to Poor
• Ice	1	Braking deceleration is significantly reduced for the wheel braking effort applied OR directional control is significantly reduced.	Poor
• Wet Ice • Slush over Ice • Water over Compacted Snow • Dry Snow or Wet Snow over Ice	0	Braking deceleration is minimal to non-existent for the wheel braking effort applied OR directional control is uncertain.	Nil

2.7.4 Testing of Anti-Skid System Components

The operating principle of the anti-skid system is described in paragraph 2.1.2. The purpose of the validation testing was to determine whether the components had any anomaly that could have affected braking performance during the occurrence. Brake system related FDR data is discussed in paragraph 2.5.1.

The testing took place in the United States at the brake system manufacturer's and its build-to-print supplier's facilities. Representatives of the brake system manufacturer, the airframer, TSB, FAA, and SIAF attended the testing of the hydraulic components. In addition, representatives from the supplier of the anti-skid control unit (ASCU) attended the ASCU testing. The validation plan included the testing of the two anti-skid control valve (ASCV) units, one of which controls the brake units on the inboard mainwheels and the other controls the brake units on the outboard mainwheels. The validation of the ASCU, which controls ASCV operation, included testing and fault data review.

The identification data on the components showed that they had been installed on the aircraft during manufacture. Hydraulic fluid samples were taken from the ASCV units before testing. Only a small amount of fluid was extracted from the units, and no anomalies were observed.

ASCV tests consisted of a simulation test to investigate system performance including brake pressure modulation at a low temperature, and an abbreviated functional test. After completing the tests, the ASCV units were partially dismantled for visual examination of the main components.

The functional tests investigated ASCV operation during a simulated landing on a slippery runway. For this purpose the ASCV units were cooled to a temperature similar to the ambient temperature at Turku at the time of the occurrence. The first item was the testing of the touchdown protection function, which prevents brake pressure application and recirculates all fluid to the reservoir. This was followed by a test in which 3,000 psi pressure, which is the maximum pressure in the aircraft's brake system during full brake pedal application, was applied to the ASCVs. Under this condition, the ASCVs cycled brake pressure in the same manner as during landing on a slippery runway. The test was run on each brake port on both ASCV units, both at a low temperature and at ambient temperature. The test was run multiple times on the ASCV that controlled the brake unit on the left outboard mainwheel since this pressure had a different pressure-versus-time profile compared to the other profiles.

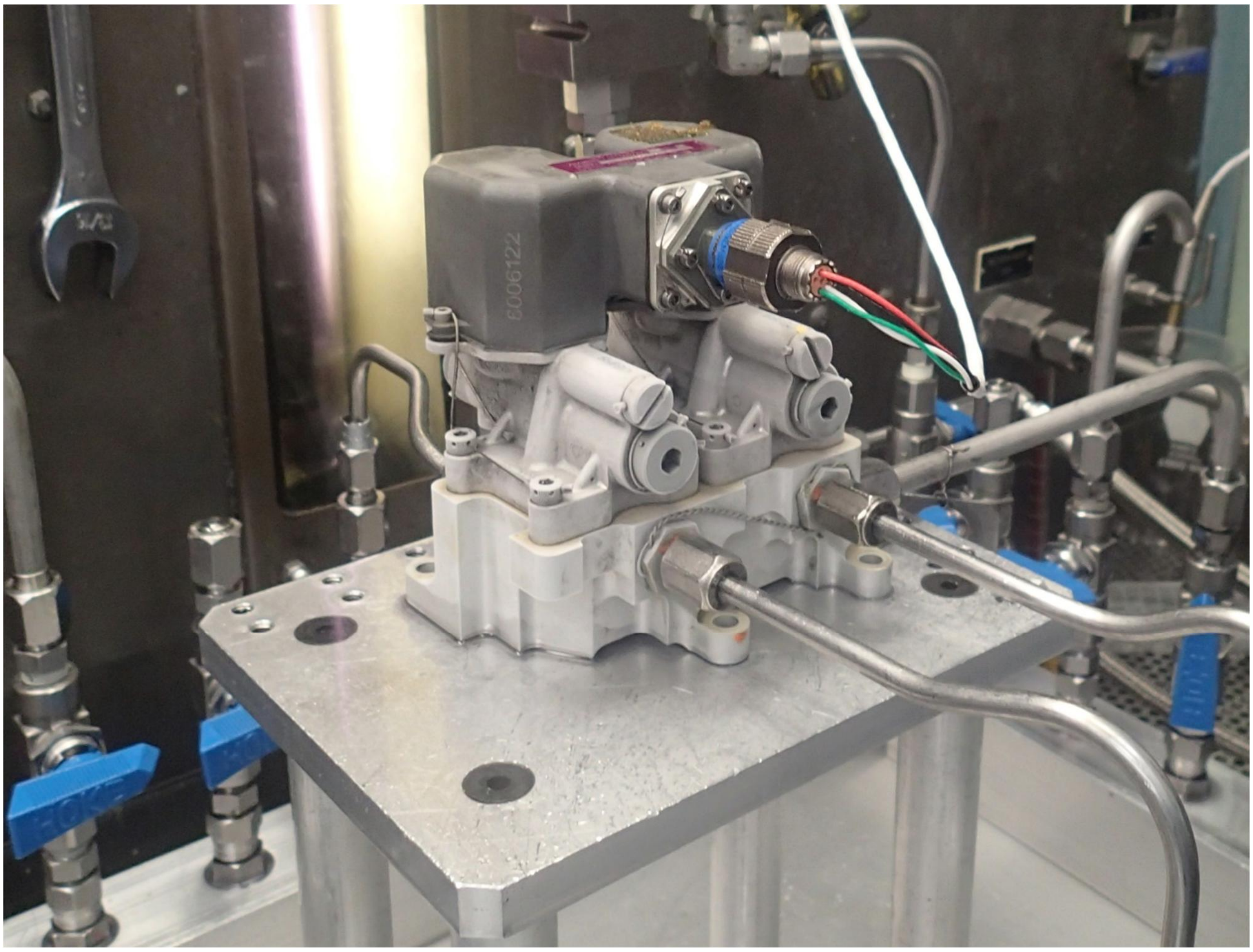

Figure 12. A cooled-down anti-skid control valve unit on the test stand (Photo: SIAF)

A total of 56 parameters were measured during testing on the two ASCV units and their two brake ports. Five parameters showed deviations from the limits set for a respective new production component. The deviations were related to hysteresis between the input signal current and the brake pressure gain at 500 psi and to the elapsed time between the input signal activation and the transient brake pressure response. The deviations were not significant and are commonly found during the testing of returned components. One deviation was observed during testing on the brake port for the left outboard wheel since it showed an anomaly in pressure gain on brake application during the landing roll. The elapsed time from the input signal activation to the start of the pressure drop at this port was 0.0118 s, while the maximum requirement is 0.010 s.

After testing, the ASCV units were partially disassembled to visually examine the spools, pistons, and filters. When the protective caps were removed, the spools slid out under their own weight with the exception of the spool in the right outboard brake control valve. After lubrication with hydraulic fluid, also this spool slid out under its own weight. This stickiness may have contributed to the large hysteresis observed at the port during the pressure gain test. No anomalies were observed on the spools and pistons. The hydraulic filters on the ASCV unit controlling the outboard wheel brakes had more contamination than the filters removed from the other unit.

The ASCV tests showed no anomalies that could have contributed to the observed inconsistent performance of the brake unit on the left outboard wheel.

ASCU validation started by examining the fault count data which showed faults logged over the last 63 flights. A review of the earlier faults revealed no anomalies that could have contributed to the occurrence. Some faults were related, among others, to excessive brake temperatures, discrepancies between wheel speeds, and parking brake application, while others had possibly been logged during maintenance and testing. No faults had been recorded during landing on the occurrence flight.

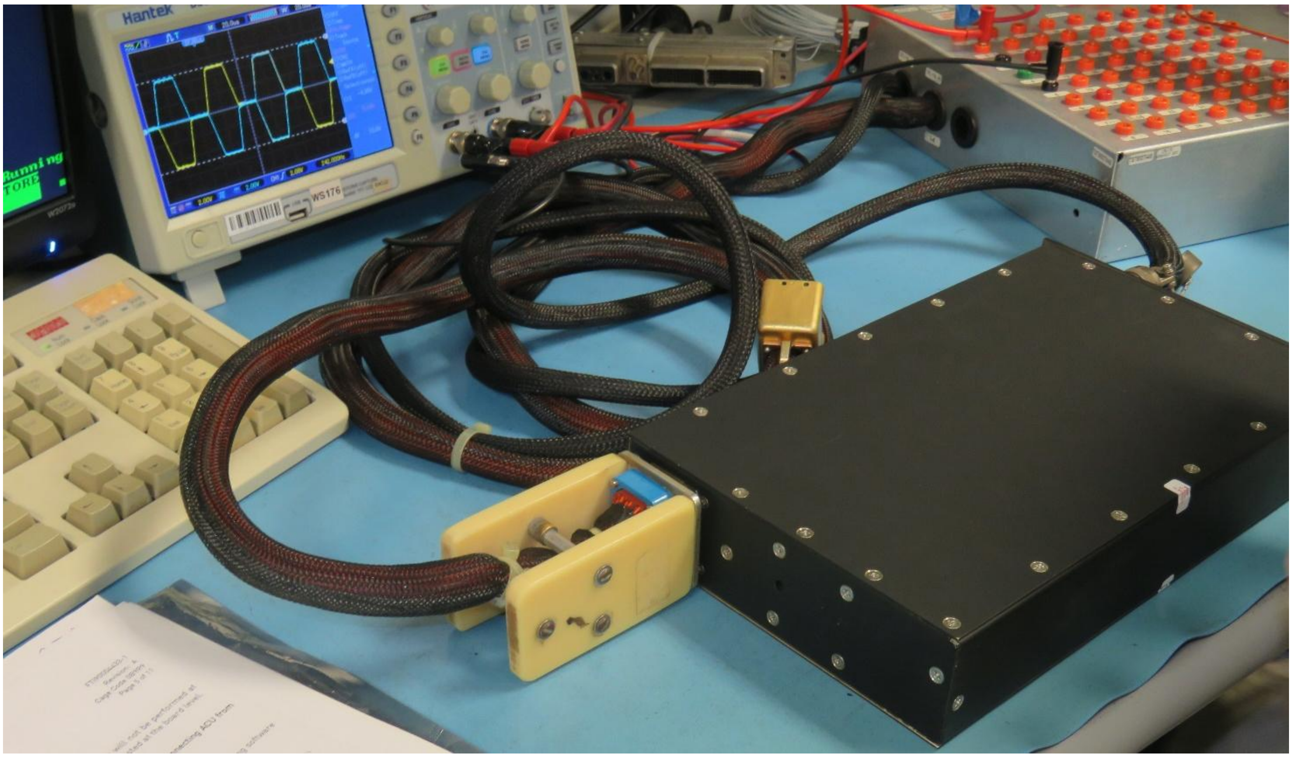

Figure 13. The anti-skid control unit under testing (Photo: Projects Unlimited Inc.)

The ASCU was subjected to functional validation that is done on returned or overhauled units. The validation plan calls for the sequential testing of the ASCU functions. These tests were repeated after temperature soaks at -40 °C and +70 °C. One failure occurred during the testing after the heat soak and was related to the test signal for the left outboard wheel brake. The anomaly was traced to a pin in the test connector that is only for ASCU test purposes and software uploads and updates and is not used on in-service aircraft. After cleaning the connector, the ASCU passed functional testing.

The ASCU tests showed no anomalies that could have contributed to the observed inconsistent performance of the brake unit on the left outboard wheel.

2.7.5 Damage to Tires

All four mainwheel tires exhibited identical damage. A worn region similar to the size of the tire footprint was evident on each tire. On some parts of the tires, wear had exposed the plies. Tires that had contacted the runway edge lights showed damage caused by the light fixtures and their mountings. No other damage that could have been incurred during the occurrence was observed in the treads or other areas of the tires. None of the tires had deflated. The nosewheel tires were undamaged. The mainwheel tires came from two manufacturers.

Table 8. Mainwheel tire particulars

Position	Left outboard, #1	Left inboard, #2	Right inboard, #3	Right outboard, #4
Manufacturer and model	Goodyear Flight Leader	Dunlop*	Dunlop*	Dunlop*
Country of manufacture	Thailand	United Kingdom	United Kingdom	United Kingdom
Size	H36x12.0-18	H36x12.0-18	H36x12.0-18	H36x12.0-18
Ply rating**	18	18	18	18
Speed rating	225 mph	225 mph	225 mph	225 mph
Load rating	21,525 lb	21,525 lb	21,525 lb	21,525 lb
Skid depth	0.33 in	0.33 in	0.33 in	0.33 in
Part number	362K82-1	DR32118T	DR32118T	DR32118T
Serial number	63415724	17236145	17242345	17184099
Date of manufacture	2016/12/06	2017/08/24	2017/08/30	2017/07/03

* Goodyear Flight Leader was the only tire type approved and listed by Bombardier for the CRJ900.
** Indicates the load rating of a tire based on the number of fiber plies.

Figure 14. Damage to the mainwheel tires. The tires are arranged to correspond to their position on the airplane as seen from the rear. (Photos: CityJet)

Tracks on the runway and snow were used to determine the sequence in which the tires struck the runway lights. Tire #3 broke the first light, tire #2 struck the three next lights, and tire #4 contacted the fifth light.

FDR and FADEC data show that the wheels barely started to rotate on touchdown. Wheel speed after approximately 2 s from touchdown was 0–3.4 kt, while the airplane was at that point traveling at approximately 150 kt groundspeed. After approximately 5 s from touchdown, the brake pressures started to increase, and the wheels locked. They subsequently remained locked over approximately 2,050 m, or for almost the entire length of the landing roll. Since none of the tires deflated, friction between the tires and the runway remained extremely low throughout the landing roll.

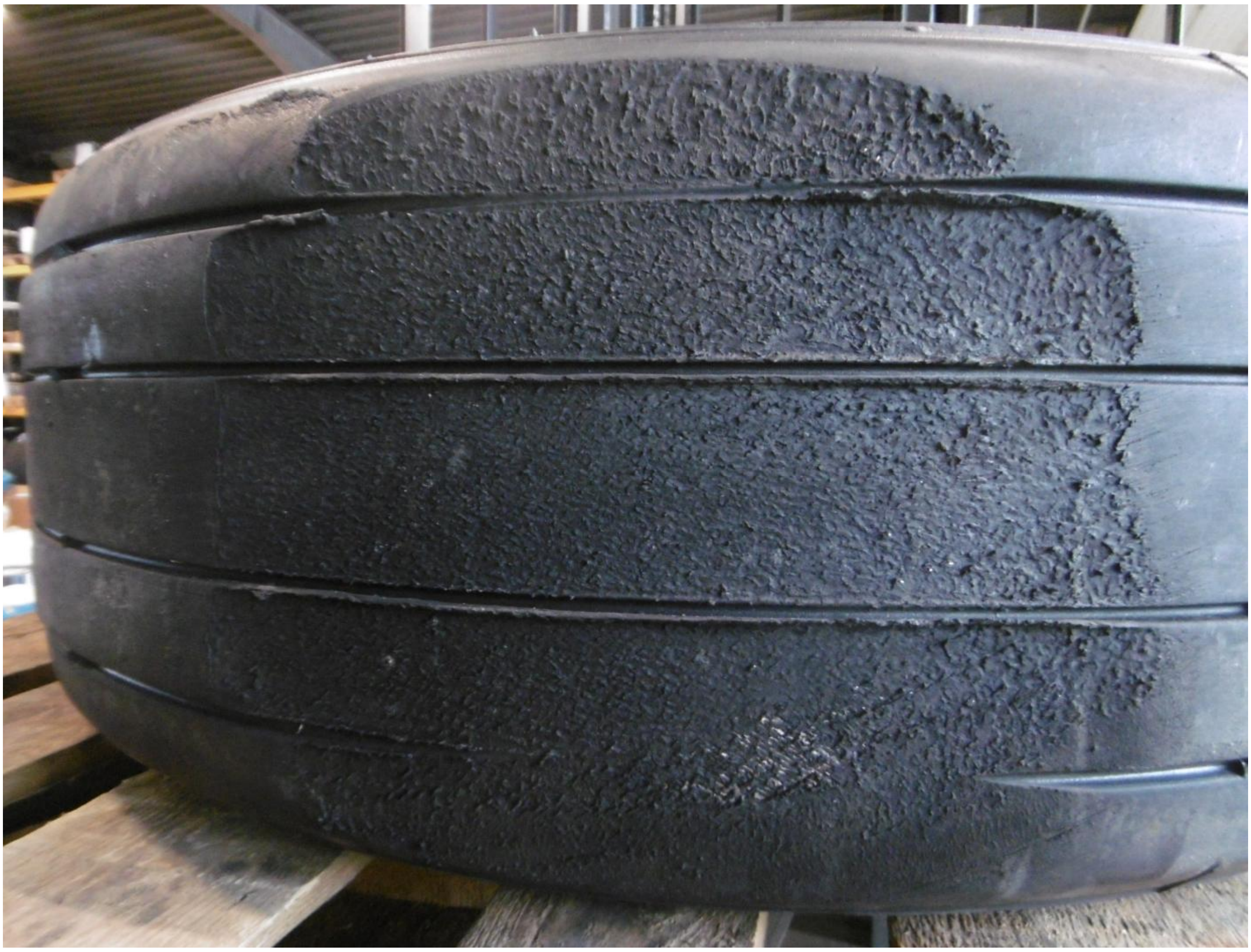

Figure 15. Mainwheel tire #1. Evidence of reverted rubber hydroplaning is apparent on the tread. The tire did not contact the runway edge lights. (Photo: CityJet)

The accredited TSB[27] subject matter expert representative supported the evaluation of the tire damage. An estimate of the damage mechanism was based on photographs and occurrence data. The report states that all four mainwheel tires exhibited flat regions of reverted rubber with a similar size and shape. In tire #2, severe scoring extending into the plies was present at the damaged area. The nosewheel tires were undamaged.

Considering runway surface conditions and the fact that the air temperature was around freezing, it is likely that the runway excursion was caused by hydroplaning. The “burn marks” on the mainwheel tires are typical of reverted rubber hydroplaning and indicate that the wheels were locked during braking on a wet runway. Similar damage occurring during runway excursions have been noted in TSB investigations. Additional damage to #2 tire most likely occurred on impact with the runway edge lights.

[27] Transportation Safety Board of Canada

3 ANALYSIS

3.1 Analysis of Occurrence

A SIAF-developed format of the AcciMap approach[28] was used to support the analysis of the occurrence. The following text is arranged in accordance with an AcciMap diagram created during the investigation and shown below.

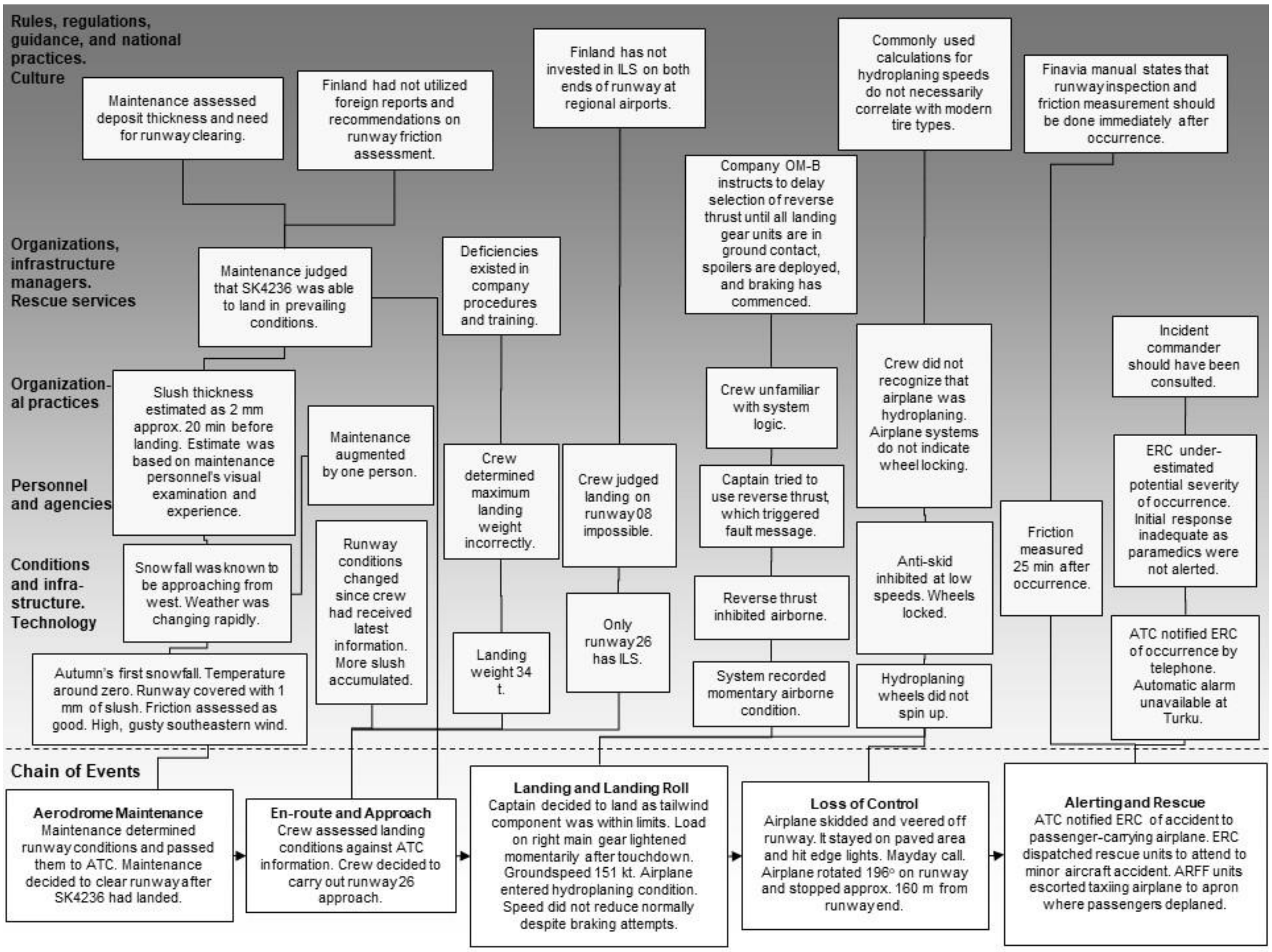

Figure 16. AcciMap Diagram

3.1.1 Aerodrome Maintenance at Turku

Runway conditions were assessed 21 min before the flight landed, and the estimate was passed to the flight crew. Heavy snow was falling at the aerodrome, and therefore runway conditions were changing rapidly due to slush accumulation. Maintenance personnel did not conduct new measurements before the landing of the flight since they estimated that the conditions were adequate for the landing of the arriving flight and the departure of a subsequent flight. They had decided to clear the runway after the latter flight had departed.

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[28] The occurrence is depicted as a chain of events along the bottom of the diagram. The identified decision-makers and other regulatory actors are on the extreme left. The steps in the chain of events are analyzed at all levels from bottom to top. The lower levels help understand how the occurrence developed, and by moving up the reader can study higher-level national or international factors and contributors. Rasmussen, J. & Svedung, I. (2000) *Proactive Risk Management in a Dynamic Society.* Karlstad, Sweden. Swedish Rescue Services Agency.

Since they did not adjust their actions in view of the changing conditions, the runway conditions transmitted to the flight crew were not representative of the conditions prevailing at the time of landing.

3.1.2 En-route and Approach

The flight crew was well aware of the changing wind conditions and monitored the winds closely. However, they were not informed of slush accumulation on the runway. This was caused by the rapidly intensified snowfall and resulted in a condition not evident from the SNOWTAM. The last accurate data on the slush deposit was issued in the SNOWTAM at 2003 h, after which deposit thickness had increased significantly. The flight crew did not question the weather and runway condition data on which they based their decisions. Since they did not request updates on runway conditions they were unaware of the effects of the changing conditions and did not request the runway to be cleared.

The captain verified that the tailwind component was within the permitted limits but did not realize that the airplane was above the maximum performance limited landing weight. The estimated landing weight was approximately 33,800–33,980 kg, which was at least 1,600 kg above the maximum performance limited landing weight. This was partly due to the complexity of the performance charts (ergonomic factors could be considered here) and a possible error in the calculations. The captain completed the calculations while managing the final stage of the approach, which may have contributed to the error. The crew members did not cross-check the calculations, even though this could have revealed the discrepancy. This indicates deficiencies in CityJet’s procedures and training.

Company training syllabi contain a mandatory one-hour course on winter operations, and the company also recommends that its flight crew members attend the airframer’s courses on winter flying. The company's route network includes aerodromes that are frequently used in winter conditions, in which case special requirements related to winter flying as well as rapidly changing conditions need to be taken into consideration.

3.1.3 Approach and Landing Aids

Runway 08 would have offered better wind conditions for landing, but due to the low cloud base landing on this runway would have required an ILS approach. At Turku, only runway 26 is ILS-equipped, and therefore the flight had to land in a tailwind. Finland's regional airports have ILS at one end of the runway only.

3.1.4 Landing and Loss of Control

Touchdown occurred at the correct distance from the threshold albeit slightly right of the runway centerline. Despite a stable approach, the airplane started tracking to the right of the runway heading on touchdown, and as a result drifted to the right of the centerline. Furthermore, the wind raised the left wing, and this was not countered with aileron control. The resulting bank angle created a horizontal lift component to the right. On a crosswind landing on a contaminated runway it is particularly important to maintain the airplane track aligned with the runway heading. In addition, in the CRJ900, aileron control shall be used to compensate for any wind-induced banking tendency.

The airplane entered a hydroplaning condition at the moment of touchdown. A tailwind and a higher groundspeed, which was due to the prevailing conditions, contributed to the onset of hydroplaning. It is likely that the flight crew did not realize that the wheels were in a hydroplaning condition, and the aircraft does not have a system that would caution the crew of abnormal deceleration. It is likely that releasing the brakes, repeatedly if necessary, would have spun up the wheels, which in turn would have increased lateral grip. Aircraft systems that use wheel speed information may not operate correctly if the wheels do not rotate.

The captain had taken control on the final approach thereby assuming responsibility for all actions affecting aircraft control. During the initial phase of the landing roll, the captain indicated an inability to control the airplane. The first officer also applied the brakes but did not notify the captain of this, assuming that the captain was not applying pressure on the brake pedals or the brakes had failed. Since the captain continued braking until the airplane came to a halt, the first officer's brake application had no effect, and regaining control was therefore impossible.

CityJet's OM-B instructs to reduce the brake pressure during a skid until airplane control is regained. Momentary brake release could have caused the wheels to spin up, in which case the anti-skid system would have activated to prevent subsequent wheel locking.

The AFM gives 116 kt as the hydroplaning initiation speed. The correct threshold crossing speed would have been 141 kt (V_{ref}), but due to gusty wind the captain flew the approach at a higher airspeed. Groundspeed on touchdown was 151 kt so the possibility of hydroplaning was significant.

Hydroplaning risk can be evaluated against runway contamination and groundspeed. The formula

$$v_{hydro} = 9 \times \sqrt{tire\ pressure\ (psi)}$$

for the hydroplaning speeds of aircraft was developed and verified in various tests in the 1960s but it does not necessarily correlate with modern aircraft tires, which may enter a hydroplaning condition at lower speeds. Some reports and studies indicate that the onset of hydroplaning may occur at lower speeds. From the flight crews' point of view it is essential to recognize the level of the hydroplaning risk during each landing so they can focus on braking techniques and the prevention of wheel locking.

Reverse thrust was not available above reverse idle since the airplane systems recorded an airborne condition and the thrust reverser system was inhibited by FADEC. If reverse thrust is selected prematurely during landing it cannot be regained without specific flight crew actions. In order to use reverse thrust, the flight crew should have selected the reversers stowed. This procedure was unknown to the flight crew. Paragraph 2.4.9 of OM-B contains guidance on the use of reverse thrust on landing. No action was carried out in order to reselect the reversers after the premature selection of the system, which had triggered a FADEC FAULT message. The AFM contains instructions after a FADEC FAULT indication during any phase of a flight. This indication may be displayed for several reasons and it has no bearing on a thrust reverser system malfunction in particular.

CityJet's OM-B contains instructions that should be followed if the airplane starts to skid during a crosswind landing. According to the manual, reverse thrust should be reduced or even canceled, which would improve aircraft control. However, reverse thrust was at idle and therefore unavailable. With reverse thrust available, the wheels would still have entered a hydroplaning condition, but would probably have exited this condition as speed decayed. Reverse thrust is most effective at high speeds.

The captain was facing a challenging situation, in which stress factors included a firm landing, a slippery runway, lateral forces acting on the airplane, and unexpected thrust reverser and braking performance. The situation was conducive to human errors despite an individual's familiarity with the applicable procedures.

3.1.5 Post-Incident Actions at Aerodrome

Aerodrome maintenance was aware of the impending weather change and prepared to ensure the smooth flow of air traffic by calling an additional person to report for duty. Maintenance work on the movement area was interrupted by the occurrence since workers had to man the rescue vehicles. Finavia's operational instructions for aerodrome maintenance in incidents and accidents state that the focus of post-incident actions is *to prevent further damage and verify the conditions at the time of the incident*. Rescue department units had arrived at the scene by the time the airplane had stopped on the apron and the passengers were deplaning so further damage was prevented, and maintenance could conduct a runway inspection as per the manual. Friction measurement began approximately 25 min after the occurrence and was followed by photographing the tracks left by the airplane. It is essential for an investigation that the conditions at the time of an occurrence are verified as carefully as possible, which can be done by measurements and by obtaining plenty of detailed imagery. Due to the delay in the runway inspection, incomplete verification of the circumstances and continuing heavy snowfall precluded accurate determination of runway conditions at the time of the occurrence.

The foregoing instructions further state that ARFF vehicles should carry a ready-to-use camera. However, the camera cannot be used to good effect since rescue crew members will be engaged in the actual rescue operation. Some Finnish aerodromes have rescue vehicles fitted with automatically-operated video cameras to capture imagery that will subsequently be useful for investigation purposes and can also be used in ARFF training. Similar camera installations are found in vehicles of the police and rescue departments.

3.2 Analysis of Rescue Measures

The first officer correctly decided to transmit the mayday call since by that time airplane control had been lost and there was a danger of significant structural damage to the airframe and serious injury to the occupants.

ATC notified the ERC of an accident involving a passenger-carrying airliner and told that the flight crew had indicated there was no apparent damage or injuries. The ERC alerted rescue units to respond to *a minor aircraft accident,* even though the risk assessment model and related instructions call for an alert for *a major aircraft accident* when the airplane involved is a passenger-carrying airliner. On the other hand, the foregoing instructions state that an accident of which sufficient information is not available is to be classified as *a minor aircraft accident,* but the risk assessment shall in this case be always verified together with the incident commander. Response to the occurrence under investigation remained inadequate, partly because no paramedic units were alerted. The criteria given in the risk assessment model for alerting paramedic units are ambiguous. The seriousness of the ground-loop was not evident at first, and damage to the airplane and the runway edge lights went as yet undetected. Information of possible injuries was also initially unavailable. The picture clarified gradually as further information of the sequence of events and airplane damage came in.

It is possible that any physical injuries were left unidentified since all passengers were not interviewed or their condition was not assessed by paramedics or other health care professionals. An event of this kind may also impose mental stresses. The assessment of the passengers' condition and any subsequent guidance to get crisis help or other support remained undone.

The condition of the airplane before taxi was inspected from the rescue vehicles using searchlights for illumination. This enables the detection of major damage and fluid leakages. The taxiworthiness of the airplane could be ensured by checking the condition of the landing gear and tires and inspecting the airplane for any other possible damage. The flight crew would have been in the best position to assess the effects of any damage. The two ARFF units alerted to the scene were manned by the operator only; therefore, if the operator had exited the vehicle to inspect the airplane, the vehicle would have been left unattended.

The controller alerted the ERC by telephone. At the same time, the controller was communicating with the flight crew – that had just transmitted the mayday call – and ARFF and was therefore unable to communicate immediately with the dispatcher although the line was open. This caused delay in the ERC's alerting the rescue department units. A push-button operated alarm system would have considerably reduced the time required for the alarm itself and its processing in the ERC, and the uncertainties that now affected the risk assessment in the ERC would have been avoided. Push-button alarm systems are currently in use, among other aerodromes, at Helsinki-Vantaa and Tampere. Any other simultaneous aircraft movements would have further and markedly increased the controller's workload, which in turn would have further lengthened the delay in notifying the ERC of an emergency.

The controller advised the ERC that the airplane was taxiing to the apron and everything was in order. According to the emergency response procedures, a controller should relay additional information to the ERC only when LENTO P3 is not the incident commander. In all other cases, LENTO P3 will relay the controller's additional information to arriving rescue units. This will give the arriving units the most recent accurate information of the situation on the scene.

4 CONCLUSIONS

Conclusions encompass the causes of an accident or a serious incident. Cause means the different factors leading to an occurrence as well as relevant direct and indirect circumstances.

1. Aerodrome maintenance decided to clear the runway after an arriving flight had landed and a departing flight had taken off. The decision was not reviewed even though weather was changing rapidly and continuous snowfall increased the thickness of the slush layer on the runway.

   Conclusion: Long-term runway maintenance planning is not possible under rapidly changing weather conditions.

2. The flight crew did not question the weather and runway condition data on which they based their decisions. The flight crew monitored wind data closely.

   Conclusion: Some time had passed from the preparation of the previous SNOWTAM. Personnel at the aerodrome knew that snowfall was intensifying. SNOWTAM reliability degrades fast under rapidly changing weather conditions.

3. The airplane was above the maximum performance limited landing weight on landing.

   Conclusion: The multi-step procedure required to determine the permitted landing weight using the tables provided for the purpose contributed to an error in weight calculations.

4. At Turku, only runway 26 is ILS-equipped.

   Conclusion: The flight crew elected to conduct a tailwind landing on runway 26 because they considered a runway 08 approach impossible due to the lack of ILS. Finland's airports, with the exception of Helsinki-Vantaa, have ILS at one end of the runway only.

5. Landing was firm; therefore, weight on the right main landing gear lightened as the oleo leg extended after touchdown, the extension reaching a point where the airplane systems sensed an airborne condition. The thrust reverser system, although armed, was unavailable after touchdown.

   Conclusion: The flight crew was not familiar with reselecting the thrust reverser system in case of it being inhibited.

6. The airplane entered a hydroplaning condition at the moment of touchdown due to the high groundspeed and a slush deposit on the runway.

   Conclusion: Anticipating the possibility of hydroplaning enhances situational awareness and prepares for a necessary action if the airplane enters a hydroplaning condition.

7. Hydroplaning prevented the wheels from spinning up to a required speed and therefore the anti-skid system did not activate. The captain's brake application, which was later augmented by simultaneous brake application by the first officer, resulted in the wheels remaining locked until the airplane came to a halt.

   Conclusion: The flight crew did not recognize a hydroplaning condition and the fact that the wheels were not rotating.

8. The equation used to determine hydroplaning and hydroplaning speeds was verified in tests in the 1960s. The values derived from the equation do not necessarily correlate with modern aircraft tires, which may enter a hydroplaning condition at lower speeds.

   Conclusion: More knowledge, reports, and possibly research will be needed for the reliable determination of the hydroplaning speeds of modern aircraft tires.

9. Since aileron control was not applied throughout the landing roll, the airplane started to veer towards the right edge of the runway, pushed by the wind.

   Conclusion: In the CRJ900, the application of aileron control is important in order to maintain airplane control during a crosswind landing.

10. The verification of the prevailing runway conditions began approximately 25 min after the occurrence. Since the conditions were changing due to the snowfall, the runway conditions at the time of the occurrence were, perforce, based on estimates.

    Conclusion: It is essential for investigation purposes that the prevailing runway conditions are determined immediately after an occurrence.

11. The controller called the ERC, which alerted rescue units to respond to *a minor aircraft accident.* Paramedic units were not alerted, and the incident commander was not consulted about the matter.

    Conclusion: When a controller makes an emergency call while simultaneously attending to other duties, the processing time will increase and the risk assessment at the ERC will be affected by uncertainties.

5 SAFETY RECOMMENDATIONS

5.1 Runway Maintenance

Information of runway conditions as received by the flight crew may differ considerably from the actual landing conditions when weather is changing rapidly.

In the occurrence under investigation, the thickness of the slush deposit was clearly on the increase, but this information was not passed on and the runway was not cleared.

The Safety Investigation Authority Finland recommends that

> *Finavia reviews the current methods for runway condition assessment, runway maintenance, and response to changing conditions, and on the basis of the review implements the necessary changes. [2018-S46]*

5.2 CityJet Instructions on Performance Calculations

The company tables used for performance calculations are complex and not easily deciphered.

The Safety Investigation Authority Finland recommends that

> *the Irish Aviation Authority (IAA) oversees that the methods used by CityJet for performance calculations are adequate and ensure safe operation under different circumstances. [2018-S47]*

The importance of accurate performance calculations and skills acquired through training are accentuated in winter conditions.

5.3 Knowledge of Thrust Reverser System Logic

The thrust reverser system on the CRJ900 is inhibited when it is selected in flight. If reverse thrust is selected prematurely during landing it cannot be regained without specific flight crew actions.

The Safety Investigation Authority Finland recommends that

> *Transport Canada (TC) oversees that Bombardier provides operators with information on the logic of thrust reverser system operation in various situations. [2018-S48]*

5.4 Hydroplaning and Tires

The risk of hydroplaning sometimes goes unnoticed or is not recognized owing to the fact that runway deposits are often rather thin. The currently observed hydroplaning speeds are often calculated using an equation that does not necessarily correlate with modern aircraft tires.

The Safety Investigation Authority Finland recommends that

> *Transport Canada (TC), as the CRJ series airplane type approval authority, oversees that Bombardier demonstrates that hydroplaning speed are determined in a sufficiently reliable manner for the tire types currently used in airplanes. [2018-S49]*

The effects of slush and other deposits than water on hydroplaning speeds shall also be examined.

5.5 Processing of Aircraft Accident Alarms in Emergency Response Centers

An air traffic controller cannot discontinue controlling duties for the duration of an emergency call. This will lengthen the processing time of an alarm and delay its dissemination. Disruptions in emergency calls will hamper the risk assessment at the ERC and the classification of the incident.

The Safety Investigation Authority Finland recommends that

> *the Ministry of Interior together with the Emergency Response Center Agency investigate ways of finding a modern technical solution that would facilitate quick forwarding of an alarm from an air traffic control facility to an ERC. [2018-S50]*

5.6 Implemented Measures

There are no known safety actions.

Helsinki, October 23, 2018

Ismo Aaltonen   Pekka Orava   Timo Naskali

Petri Koistinen   Mika Kosonen

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Van Es GWH. (2001) Hydroplaning of Modern Aircraft Tires. National Aerospace Laboratory NLR. NLR-TP-2001-242

Investigation Material

1) Flight safety reports filed on the occurrence
2) Reports filed by flight crew, CityJet
3) Report filed by maintenance, CityJet
4) Report field by Turku aerodrome maintenance, Finavia
5) Notice of investigation, Police
6) Bombardier Aircraft Level Observations, CITYJET CRJ900 EI-FPD (S/N 15401), Loss of Control During Landing, Serious Incident Turku, Finland 25 October 2017, Bombardier
7) Landing Performance Comparison Study (CRJ900 EI_FPD (A/C 15401) Turku Serious Incident, Bombardier
8) CRJ900 EI-FPD (S/N 15401) – Loss of Control and Runway Excursion During Landing, Memo, Bombardier
9) Engineering laboratory report, Analysis of Tires, CL-600-2014 (CRJ-900), EI-FPD, Transportation Safety Board of Canada
10) Company Safety Investigation Report CIR 05/2017, CityJet
11) Safety Investigation Report CRJ900 Anti-Skid Control Valve and Anti-Skid Control Unit Assemblies BCY Landing Roll Incident, TKU Airport, 25-October-2017, Meggit
12) G.W.H. van Es, Review of the state of current knowledge regarding tyre braking performance, anti-skid systems, and modern aircraft tires on water contaminated runways
13) Winter Operations, Friction Measurements and Conditions for Friction Predictions, Main Report, SL2011/10, Accident Investigation Board Norway
14) Licenses and ratings of flight crew and air traffic controller
15) CRJ900 airplane technical data and documentation
16) EI-FPD damage assessment documentation
17) EI-FPD logbook October 25 to November 19, 2017
18) EI-FPD loadsheet, SK4236 November 25, 2017
19) CityJet documents
20) Turku aerodrome exercise plans 2015–2017
21) Safety management system manual, Finavia, v.1.0
22) Air Navigation Services Finland documentation
23) Operational instructions for aerodrome maintenance in incidents and accidents, Finavia, v.1.3
24) Weather data November 25, 2017
25) EI-FPD cockpit voice recordings
26) Occurrence-related radio communications recordings from Turku aerodrome air traffic control
27) EI-FPD flight data recorder data
28) Flight data recorder -derived animations
29) Procedures for aircraft accident investigation, Police, December 13, 2013
30) Occurrence-related rescue department and paramedic service material
31) Occurrence-related emergency response center material and instructions
32) Occurrence-related emergencies reports from rescue department's action log and assignment register
33) Validation test plan and test results of anti-skid system components
34) Occurrence-related photographs, Finavia November 25, 2017
35) Occurrence-related photographs, Police November 25, 2017

SUMMARY OF COMMENTS TO DRAFT FINAL REPORT

The draft final report was submitted for comments to the Finnish Transport Safety Agency, Southwestern Finland Rescue Department, National Police Board, Finavia, ANS Finland, Swedish accident investigation authority, Irish Aviation Authority, Emergency Response Center Agency, CityJet, Bombardier, European Aviation Safety Agency, Transport Canada, and the crew of the occurrence flight. Pursuant to the Safety Investigation Act, no comments given by private individuals are published.

The Finnish Transport Safety Agency (Trafi) commented that the regulations that were in place for the aerodrome and the operator at the time of the occurrence were based on the AGA M3 series of national aviation regulations. Turku aerodrome was issued an EU-certificate on December 7, 2017. From that date on, the regulations governing the infrastructure and operations at the aerodrome have been in compliance with Commission Regulation (EU) No 139/2014. Trafi points out that the report does not indicate that the functioning and effectiveness of the applicable safety management systems, both before and after the occurrence, had been investigated.

According to Trafi, investigation into the safety management systems of air operators and aerodrome operators would be important, especially in view of the requirements of Commission Regulation (EU) No 965/2012 on air operations. In conjunction with this, the roles of organizations in developing pilots' knowledge base, decision-making, and crew resource management (CRM) skills as well as related responsibilities should be looked at.

While Trafi endorses the safety recommendations it states that the recommendation pertaining to guidance on performance calculation should also be addressed to CityJet; in addition, it should be ensured that flight crew members are given adequate training. The recommendations should also consider organizations' responsibilities and the role of the safety management systems.

The Southwestern Finland Rescue Department commented that the presented facts essentially cover the events from the department's point of view. The department's comments included a small number of specifying amendments to the text.

The National Police Board's comments brought up the fact - that was noted in the report - that the patrol alerted to the scene did not breath-test the flight crew in accordance with the applicable directive. A board directive on the investigation of aircraft accidents states that, among other tasks, the flying condition of the crew is to be determined. The board states that the issue will be given more attention in training to ensure adherence to proper procedures during similar occurrences in the future.

Finavia had no comments on the draft report.

ANS Finland proposed a small number of specifying amendments to the text.

Swedish accident investigation authority (SHK) proposed a small number of specifying amendments to the text.

The Irish Aviation Authority (IAA) presented a small number of comments related to weight calculations and related tables. About the recommendation concerning performance calculations the IAA states that the tables are industry standard used by multiple air operators. The IAA wishes clarification on what additional oversight is recommended, bearing in mind that the IAA may not be asked to exceed the applicable EASA implementing rules in this regard.

The Emergency Response Center Agency presents in its comments specifying remarks and answers in matters related to alerting and rescue services. The agency's comments are based on the draft report and data extracted from ERC assignment records and alert logs. The agency states that the first alert call was interrupted several times, and therefore the dispatcher, who was receiving information from the air traffic controller and background radio communications, remained unaware of the seriousness of the occurrence. The controller's message indicating that the airplane was undamaged and there was no injury to persons was considered significant. The number of airplane occupants was reported in a subsequent call, in which the controller also advised that the airplane was taxiing to the apron and everything was in order. The occurrence should have been classified as a *major aircraft accident* if the criteria laid down in the risk assessment model had been adhered to exclusively. In a confusing situation, the dispatcher discussed the matter with the on-duty supervisor. They considered all facets of the situation and decided to classify the occurrence as an *accident of unknown type,* which is coded and recorded as a *minor aircraft accident*. The agency states that this decision may have been partly due to the fact that an assignment classified as a *major aircraft accident* initiates an alert that will involve multiple agencies and operators including rescue service units and paramedics. From the agency's point of view, which is based on what was heard on the background during the emergency call and on information received in the second call, alerting the rescue services to respond to a *major aircraft accident* could have resulted in dispatching an unnecessarily large number of units.

As for paramedic units not having been alerted, the agency says that, in case of every aircraft accident, paramedic units are issued an urgency class A alert if certain criteria are met. In this particular occurrence those criteria were not met so an alert was not issued. The agency, however, says that some ambiguity is apparent in the current instructions, since paramedics are always alerted to respond to every "full aviation emergency" situation. The agency states that the ambiguity should be removed and the procedures standardized.

The agency concurs with the investigators' conclusion in that the dispatcher should have clarified the matter further with the incident commander in a situation that eventually led to a risk assessment that, due to the confusing nature of the occurrence, proved to be lower than prescribed in the published procedures. The situation could also have been clarified by reporting that paramedics had not been alerted. The agency states that the aerodrome emergency response notification procedures are not included among the documents issued to the agency for aircraft accidents; therefore, dispatchers are unfamiliar with the chain of command and reporting system in place within the aerodrome area. These matters should be taken into account in the applicable instructions as well as during training and exercises.

The agency concurs with the safety recommendation on the processing of aircraft accident alerts. The procedure that is in place at Helsinki-Vantaa airport and on the aerodromes in Pirkanmaa region could be implemented nationwide at all controlled aerodromes. The related procedures would be promulgated by rescue service agencies. The installation of a technical alerting system will also require the participation of air navigation service providers and necessitate amendments to rescue service agencies' procedures. The applicable response assessment procedures would also need to be revised.

CityJet proposed several detailed specifying amendments to the text. The company presents its views on the causes and contributing factors brought up in the conclusions.

Bombardier proposed several detailed specifying amendments to the text.

European Aviation Safety Agency (EASA) made a special mention of the recommendations of a theme investigation on winter operations conducted by the Accident Investigation Board

Norway (AIBN) and addressed to EASA. EASA points out that work on ICAO Global Reporting Format (GRF) has been under development since 2011 and the GRF will come into force on November 5, 2020. EASA proposed a small number of specifying amendments to the text. As for the recommendation on runway maintenance, EASA notes that parallel reviews may be under way as a consequence of the transition to the GRF, and an acknowledgement of such ongoing work would be appropriate.

Transport Canada (TC) presents detailed comments on the recommendations related to knowledge of the operating logic of the thrust reverser system and tire hydroplaning speeds. TC maintains that system descriptions are not part of the approved sections of aircraft flight manuals (AFM) and explains that the appropriate location for this type of information is the system description section of the flight crew operating manuals (FCOM), which are not TC-approved documents. As for tire hydroplaning speeds, TC holds a view that it does not define or mandate the specific equations used for determining performance, at least not as part of any particular subpart paragraph. In addition, TC's view is that the published hydroplaning speed did not appear to be relevant in this particular occurrence since the speed of the airplane was considerably higher. TC concluded its comments by stating that investigation into the matter should be carried out by the manufacturer.