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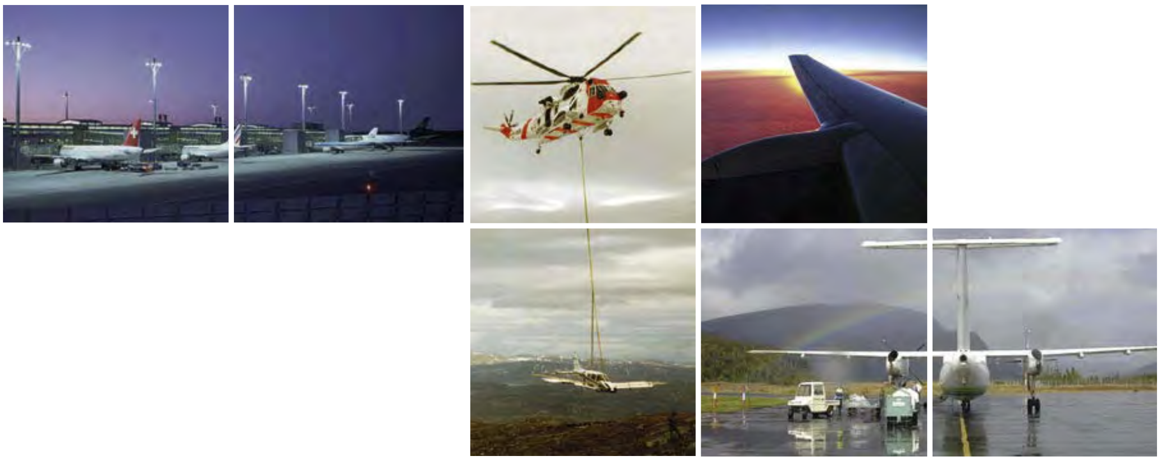

REPORT ON THE SERIOUS INCIDENT AT OSLO AIRPORT GARDERMOEN NORWAY 31 JANUARY 2008 TO BOMBARDIER CL-600-2B19, OY-RJC, OPERATED BY CIMBER AIR DENMARK

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This report has been translated into English and published by the AIBN to facilitate access by international readers. As accurate as the translation might be, the original Norwegian text takes precedence as the report of reference.

The Accident Investigation Board has compiled this report for the sole purpose of improving flight safety. The object of any investigation is to identify faults or discrepancies which may endanger flight safety, whether or not these are causal factors in the accident, and to make safety recommendations. It is not the Board's task to apportion blame or liability. Use of this report for any other purpose than for flight safety should be avoided.

Photos AIBN and Trond Isaksen/OSL

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REPORT ON SERIOUS INCIDENT

Aircraft:	Bombardier Inc. – Canadair CL-600-2B19 (CRJ200)
Nationality and registration:	Danish, OY-RJC
Owner:	NAC Nordic Aviation Contractor A/S, Billund, Denmark
User:	Cimber Air, Sønderborg, Denmark
Crew:	2 pilots and 2 cabin crew members
Passengers:	None
Location:	Oslo Airport Gardermoen (ENGM) (60°11'N 011°07'E)
Incident time:	Thursday, 31 January 2008 at 1721 hrs.

All times in this report are local time (UTC + 1 hour) unless otherwise indicated.

NOTIFICATION

On 31 January 2008 at 2005 hours, the Air Safety Manager of Cimber Air called and notified the inspector on duty at the Accident Investigation Board Norway (AIBN) of a serious incident involving one of the operator‟s aircraft of the type CRJ200 during take-off from Norway‟s main airport Gardermoen that same day. The operator had also notified the Danish accident investigation board about the incident.

In accordance with ICAO Annex 13, Aircraft Accident and Incident Investigation, the AIBN notified the authorities in the State of manufacturing Canada about the incident. The Canadian Transportation Safety Board (TSB) appointed an accredited representative who assisted in the investigation. He received support from advisors from the aircraft manufacturer Bombardier and Transport Canada (TC), the certifying authority. The Accident Investigation Board Denmark also appointed an accredited representative who assisted in the investigation.

SUMMARY

On 31 January 2008, at 1721 hours, a serious aircraft incident took place during take-off from runway 19L at Oslo Airport Gardermoen (ENGM). A Bombardier CL-600-2B19 (CRJ200) aircraft with two pilots and two cabin crew members on board suddenly lost lift on the right wing, causing the wing to drop and sending the aircraft into an uncontrolled 40-degree bank immediately after lift-off. The stall protection system activated, and the crew regained control and continued as scheduled to Copenhagen.

The investigation has shown that prescribed de-icing took place 15 minutes prior to departure, and that the wings were not cold-soaked in advance. Weather conditions were temperature at freezing, 15 kt wind and continuous precipitation in the form of aggregated, wet snowflakes. The runway was covered by slush and wet snow which had fallen after the runway had been cleared of snow and sanded 30 minutes earlier. Unintentionally, due to distraction, the system for heating the leading edge of the wing was not switched on prior to take-off. The nose wheel

was lifted from the ground at the correct speed, but at a higher than recommended rotation rate.

This incident is one in a number of similar cases. From 2002 to 2008, six CL-600 series aircraft were involved in accidents during winter conditions. The wing of the aircraft type has proven to be especially sensitive to contamination on the leading edge. After the accidents, a number of measures have been implemented to ensure that the wing is clean during take-off, and to ensure that the pilots use the correct take-off technique.

The AIBN believes that the safety measures that have been introduced have not resulted in a definitive solution to the problem. When the de-icing fluid runs off during take-off, it is essential that the leading edge of the wing is heated. On take-off from contaminated runways, spray from the nose wheel will envelop the aircraft's wing root. This source of contamination hits an aerodynamically critical area on the wing, and comes in addition to the precipitation which can adhere to the wing and disturb the airflow. The AIBN believes that it is not sufficient to depend solely on ”soft” safety barriers such as check lists and memory when the position of one switch (Wing Anti-Ice ON) can be critical to prevent a catastrophic accident during take-off. Technical or physical safety barriers in the form of design changes, automatic systems or automatic warning systems are, in the opinion of the Accident Investigation Board, necessary to obtain adequate reduction in accident risk. Alternatively, more severe restrictions for winter operations with the affected aircraft models must be introduced.

The Accident Investigation Board issues four safety recommendations in this report.

In accordance with ICAO Annex 13, a draft of this final investigation report was sent for consultation to, among others, the aviation authority in the State of manufacture Canada. The comments received from the certifying authority Transport Canada have been enclosed[1].

1. FACTUAL INFORMATION

1.1 History of the flight

1.1.1 Cimber Air flight no. SAS9242 (wet lease for SAS) from Copenhagen Airport Kastrup (EKCH) to Kristiansand Airport Kjevik (ENCN) diverted to Oslo Airport Gardermoen (ENGM) due to strong winds (wind shear) and snow with poor visibility at Kjevik. The aircraft landed at Gardermoen at 1554 hours and was directed to a remote parking stand. The passengers were taken to the terminal by bus. After some time, it was decided that the aircraft, of the type CRJ200 with registration OY-RJC, should make a position flight back to Copenhagen with only the commander, first officer and two cabin crew members on board.

1.1.2 The commander entered the terminal and planned the flight to Kastrup. After returning from the planning office, he performed the aircraft external inspection himself. There was nothing of note, except for the snow that accumulated on the wings and that there was also snow on the underside of the wings. He pushed with his hands at all spoiler surfaces and verified that they were in and locked. During the draft final report consultation, the commander has further elaborated on what he observed: *–There was a lot of ice/snow/slush on the underside, particularly on the wing and flaps on the right side."*

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[1] *Ref. ICAO Annex 13 pkt. 6.3, Note 2: Comments to be appended to the Final Report are restricted to non-editorial-specific technical aspects of the Final Report upon which no agreement could be reached*

1.1.3 The aircraft was fuelled from a vehicle. Registrations made by the oil company show that tanking started at 1640, and that 2762 litres of fuel with a temperature of 3.5 °C was filled. The amount of fuel after filling was 3000 kg (3750 litres), evenly distributed in the wing tanks.

1.1.4 According to weather observations at the airport, the precipitation was a mixture of snow and rain of moderate intensity, resulting in a visibility of about 1500 m. The precipitation was continuous during OY-RJC's ground stop. The air temperature was 0 °C and the wind was from the south-south-east, 15-18 kt with some gusts (see 1.7 for supplementary weather information). The braking action was stated to be ”medium” based on friction measurements taken at 1648 hours. Furthermore, ATIS (Automatic Terminal Information Service) stated that there was 3 mm of slush on the runway, and that the runway had been sanded (see 1.10.2 for supplementary information relating to runway status).

1.1.5 OY-RJC was equipped with a Nokia Communicator Take Off Data Computer (TODC), but it did not function despite repeated attempts, so the crew had to make take-off calculations manually. Take-off mass was estimated to 17330 kg, giving a rotation speed (V_R) of 115 kt with 20° flaps, „Wing and Cowl anti-ice ON" taken into consideration. 20° is the flaps setting for take-off on contaminated runways. Take-off decision speed (V_1) and take-off safety speed (V_2) were calculated to 109 kt and 125 kt, respectively.

1.1.6 When the crew radioed air traffic services and requested permission to start the engines, they also stated that de-icing was required. At 1703 hours, OY-RJC taxied in on the de-icing platform in the north-east (B-North) close to the threshold on 19L, which was runway in use (see Appendix B). The commander on OY-RJC established radio contact with the de-icing ”Final Release Person” (FRP). The commander agreed that the fuselage did not need de-icing as he was told that the de-icing personnel could not see any snow on the fuselage from their elevated special vehicles. The commander noticed that there was no snow present on the fuselage of the aircraft that parked next to them.

1.1.7 The wings and tail section were treated in two steps (see 1.10.3 for a detailed description of the de-icing). Step 2, applying fluid to prevent icing while the aircraft was on the ground, started at 1706 hours. The commander checked the table with guidelines for ”Hold-Over Time” (HOT) and concluded that the treatment received would provide protection for at least 20 minutes under the reported weather conditions[2].

1.1.8 OY-RJC left the de-icing platform, performed an engine run-up and received clearance to holding position for take-off. While they were waiting, an MD81 landed. The crew on this aircraft reported that the braking action was poor along the entire length of the runway. This information made the commander on the OY-RJC make a new consideration to assert whether the combination of crosswind and braking action still was within limits. The takeoff clearance for OY-RJC contained information stating that landing aircraft deemed the braking action to be “poor” and that wind was from 150 degrees at 15kt. The commander estimated the crosswind component to be 11 kt and deemed this acceptable. The first officer had no objections to the commander's reasoning and agreed that they could take off. The first officer remembered that the snowflakes fell almost vertically to the ground.

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[2] *This value applied to a different Type II fluid. The guidelines for the relevant fluid indicated a HOT of 1:00-1:35 minutes*

The commander has described visibility to be good enough to see almost the entire runway. He described that the top layer of the precipitation on the runway was white, with a grey layer underneath. The layer was transparent, not compact; the commander could see the runway surface below.

1.1.9 The first officer was Pilot Flying (PF). He was in the process of completing the last check-list items while they were positioning the aircraft on the centre line prior to take-off. Among other things, ”Wing Anti-Ice” (WAI) was to be switched on at this stage. The first officer was ready with his hand on the switch, but this item was delayed and subsequently forgotten when the afore mentioned discussion concerning whether to take-off came up. Flaps 20° was set, and ”continuous ignition” and ”cowl anti-ice” were on when the take-off started at 1720 hours. The commander instructed the first officer to limit engine run up to about 70% N1 before releasing the brakes, as the surface was slippery. Engines were set at “Thrust reference indicator in N1 window” (full thrust, not flex) while rolling, and all indications were normal.

1.1.10 The acceleration was normal. The first officer has explained that the crosswind was noticeable, but not problematic. When the speed reached 80-90 kt, he registered that the surface was slippery and that the fuselage was tending to move sideways, but he compensated with the controls and kept the aircraft on the centre line. The first officer has furthermore explained that he looked forward to becoming airborne. Upon achieving rotation speed (V_R) he made a ”firm” rotation upwards towards the attitude indicated by the flight director.

1.1.11 The commander has explained that he reacted to the rotation being excessively fast. He lifted his hand to intervene, but did not find it necessary as everything normalised at the same moment. The rotation was completed to the correct attitude according to the flight director. He therefore lowered his hand, focusing on the altitude and vertical speed indicator in preparation of raising the landing gear.

1.1.12 Suddenly, and completely without warning, the right wing dropped markedly. The first officer has explained that he perceived that the nose dropped in the same instant, and that the stick shaker engaged. The commander put a hand on the thrust levers and verified that they had take-off power. Both of them saw that they were at very low altitude and headed for the snow-covered ground. The first officer succeeded in re-establishing horizontal wings and raised the nose of the aircraft in a matter of seconds.

1.1.13 The commander has explained that he noticed a warning, EFIS comparator monitor, as control was lost, and he first feared that they had an erroneous speed indicator, causing them to rotate too early. But he could see that both the two primary and the secondary speed indicators indicated speeds above 130 kt. As soon as they had ”wings level” and he felt that the aircraft was more or less under control, he then noticed that Wing Anti-Ice had not been switched on, and he corrected this immediately. He could not see any other irregularities. The climb continued without further problems.

1.1.14 When they were certain that they had regained control, the commander checked the mass and balance calculations. The centre of gravity location was approximately in middle of the permitted range, and the stabiliser trim setting was correct; 7 EICAS (Engine Instrumentation and Crew Alerting System) units (-5 degrees). The flight controls functioned normally, and they had no abnormal indications. The commander decided to continue to Copenhagen as planned. There was no communication between the air traffic control and the crew relating to the incident. There were probably no witnesses to the incident. The two cabin crew members sat in rows 2 and 3 in the cabin and did not notice anything out of the ordinary. None of them had looked out of the windows during take-off, and the movements in the aircraft felt like turbulence to them.

1.1.15 OY-RJC landed at Kastrup at 1815 hours. After landing, the commander contacted the company and notification of the incident was immediately sent to the Danish and Norwegian accident investigation boards. Wings and wing leading edges were inspected for damage or contamination. There was nothing out of the ordinary about the condition (see 1.6.2.5). The flight recorder was removed for analysis.

1.1.16 Data from the flight recorder were downloaded at the UK Air Accidents Investigation Branch (AAIB). The data were then submitted to the Canadian TSB for analysis. The following description of the chain of events based on the flight recorder data have been obtained from the report prepared by the TSB's engineering department:

"The take-off roll commenced at approximately 16:20:43 UTC, with the flaps and the stabilizer trim set to 20 degrees and -5.0 degrees, respectively. The take-off thrust was set with engine low pressure compressor speeds (N1' s) stabilizing at approximately 85%. Left roll aileron inputs (up to ~15 degrees deflection) were applied during the take-off roll consistent with the left crosswind (wind from 150 degrees).

The take-off continued normally and at 16:21:05, the elevators moved trailing edge (TE) up to a maximum of 19.3 degrees consistent with rotation. The airspeed was approximately 119 knots indicated airspeed (KIAS) and the heading was 192 degrees magnetic (runway heading is 195 degrees magnetic). The aircraft pitched nose-up at a rate of approximately 6.1 degrees per second (deg/sec).

The aircraft lifted off at approximately 16:21:06 (left main gear squat switch changed to ‗Air') through a pitch angle of 5.1 degrees nose-up, heading 194 degrees magnetic. Within 1.8 seconds, the aircraft began an uncommanded roll to the right. Left roll aileron inputs were increased (up to the maximum deflection of ~25 degrees) and rudder was deflected to the left to 12 degrees. The roll continued to the right subsequently reaching a maximum bank angle of 39.7 degrees about 1.5 seconds later, through a radio height of 30 feet above ground level (AGL); roll rate was approximately 23 degrees per second. At the time of the roll excursion, as the pitch attitude was increasing through 13.8 degrees nose-up, the elevators moved rapidly in the TE down direction. The airspeed was approximately 127 KIAS, heading was 197 degrees, and left and right fuselage angles of attack (AOA) were 11.0 degrees and 11.7 degrees, respectively.

The pitch attitude reached a maximum angle of 14.9 degrees nose-up (target pitch was 15 degrees) at 16:21:08.5 with corresponding left and right fuselage AOA's at 11.3 degrees and 12.8 degrees, respectively. With the TE down elevator input, the pitch attitude decreased to approximately 8 degrees nose-up, reached at the same time as the maximum bank angle of 39.7 degrees. The roll then reversed direction, 23 degrees of TE up elevator was applied, and the pitch attitude increased to 11 degrees nose-up. The aircraft recovered from the roll excursion, rolling through wings level at

16:21:11. The airspeed was 135 KIAS, heading was 195 degrees, and the left and right fuselage AOA's were 8.1 degrees and 8.2 degrees, respectively. The remainder of the climb-out was uneventful and the flight continued to destination."

1.1.17 The flight recorder records no parameters related to activation of the stall protection system, SPS (systems description in 1.6.2.4). Calculations based upon recorded angles of attack, corrected for crosswind, have, however, provided a basis for concluding that the stick pusher activated and provided the rapid elevator deflection that interrupted the stall:

"The derived vane AOAs [...] exceeded both stick shaker and stick pusher thresholds, suggesting shaker activation followed by pusher during the roll excursion. The rapid TE down elevator movement occurred at the time the derived vane AOAs (both left and right, with phase advance applied) exceeded the stick pusher threshold; the rapid elevator movement was consistent with pusher activation."

1.1.18 Bombardier prepared an animation of the take-off based on data from the flight recorder. A simplified, de-identified version has been made available on Bombardier's web site as part of a training program for flight crews.

Figure 1a) Commencing take-off.

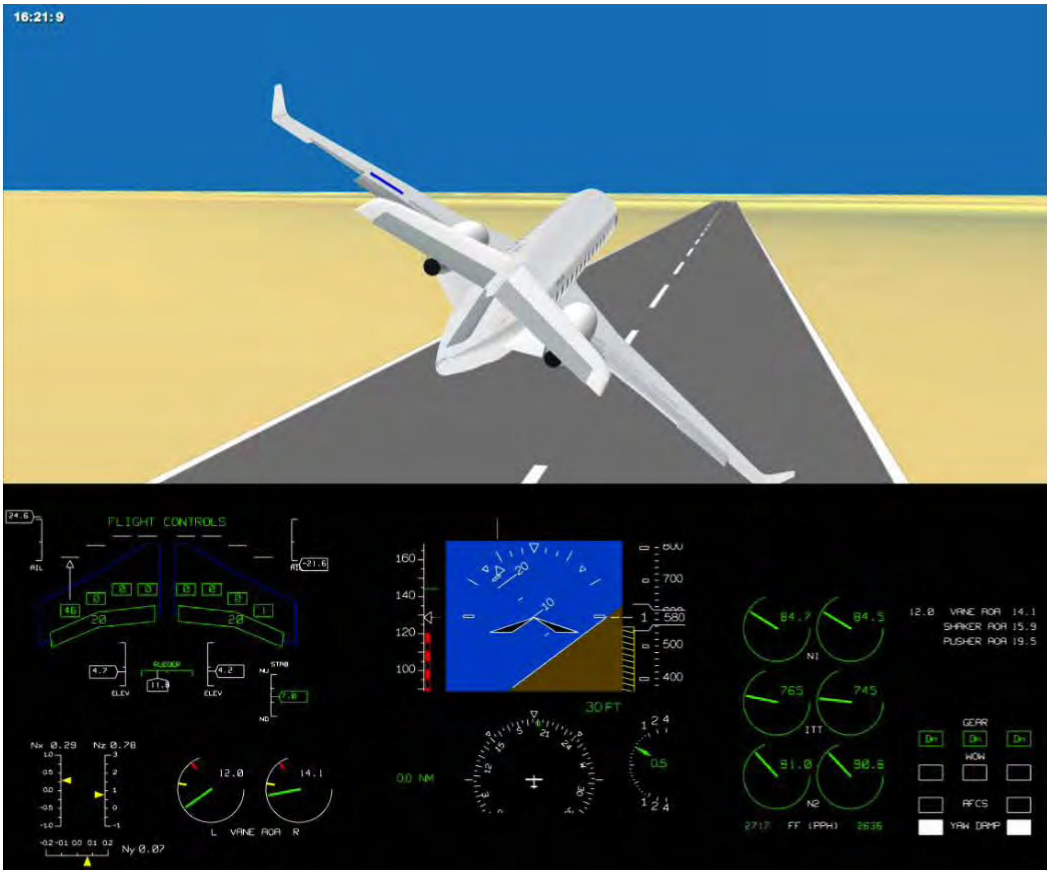


Figure 1b) Shortly before Stick pusher activates.

Figure 1: Animation of the take-off with OY-RJC. Full animation is available at http://www.aibn.no/aviation/reports/2011-09-eng. Note: The animation is based on data from DFDR. Surroundings and weather conditions are not representative for the incident in question.

1.2 Personal injuries

Table 1: Personal injuries

Injuries	Crew	Passengers	Other
Fatalities			
Serious			
Light/none	4		

1.3 Damage to aircraft

None

1.4 Other damage

None

1.5 Personnel information

1.5.1 Commander

1.5.1.1 The commander, male, 42 years old, was educated as a commercial pilot in the USA and acquired varied pilot experience in the early 1990s. He was hired by SAS in 1997, and flew as first officer on DC-9 and MD80 until February 2007. He was then hired out to Cimber Air to fly CRJ200. In late summer 2007, he obtained the

JAR-FCL Airline Transportation Pilot Licence ATPL (A) with CRJ200 rating, and has since flown as a commander. He had a valid Class 1 medical certificate without limitations.

Table 2: Flying experience commander

Flying hours	All types	Relevant type
Last 24 hours	3	3
Last 3 days	3	3
Last 30 days	50	50
Last 90 days	150	150
Total	6500	450

1.5.1.2 The commander had just completed a ten-day off duty period prior to this workday. He has stated that he felt rested. He had a meal a few hours before the incident.

1.5.2 <u>First officer</u>

1.5.2.1 First officer, male, 30 years old, educated as a commercial pilot in the USA and Sweden in the late 1990s. He was hired by Cimber Air in 2005, and had two years of experience as a first officer on CRJ200. He was the holder of a valid JAR-FCL Commercial Pilot Licence CPL (A) with Class 1 medical certificate without limitations. The most recent periodic flight training in the company (Operator Proficiency Check, OPC) was completed in the autumn of 2007.

Table 3: Flying experience first officer

Flying hours	All types	Relevant type
Last 24 hours	2	2
Last 3 days	2	2
Last 30 days	52	52
Last 90 days	153	153
Total	2588	1400

1.5.3 The first officer had just completed a five-day off duty period. He has stated that he had slept well. He had a meal a couple of hours before the incident.

1.6 Aircraft

1.6.1 <u>General information</u>

Manufacturer: Bombardier Aerospace

Type: Canadair CL-600-2B19 (Series 100) Regional Jet, CRJ200

Serial no.: 7015

Year of production: 1993

Airworthiness Review Certificate (ARC) valid until 11 May 2008

Engines: 2 General Electric CF34-3B1 turbofan engines

Total airframe hours/cycles: 31 358 hours / 25 655 landings

Maximum take-off mass: 23 995 kg

Actual take-off mass: Approximately 17 300 kg

Centre of gravity location: Approximately 19% MAC. (Permitted range for departure: 9% - 35%)

Take-off speeds for actual mass:
V_1 = 109 kt
V_R = 115 kt

Corrected for contaminated runway:
V_1 = 102 kt
V_R = 117 kt

No findings have been made indicating defects or malfunctions in OY-RJC which impacted on the serious incident.

1.6.2 Description of aircraft type and selected systems

1.6.2.1 *General*

The aircraft type Bombardier Inc. Model CL-600-2B19, a "Regional Jet airliner" is also known under the designations CRJ200 and Challenger 850. The first delivery of the aircraft type took place in 1992. In total, 1021 of the CRJ series aircraft, standard variant taking up to 50 passengers, were delivered until production ceased in 2006 (source: Jane"s All the World"s Aircraft 2009-2010). The corporate/ business edition Challenger 850 is still in production.

CL-600-2B19 (Regional Jet Series 100) was certified in accordance with the US Airworthiness standards FAR-25 (including Amendments 25-1 to 25-62), and on this basis received a Canadian type certificate on 31 July 1992 (see Transport Canada Type Certificate Data Sheet (TCDS) no. A-131). In parallel with the Canadian certification, the aircraft type was also certified in accordance with the JAA airworthiness requirements JAR 25 (including Amendment 13), and received a European type certificate on 15 January 1993 (See EASA TCDS IM.A.023).

The certification basis for the European certification states that the aircraft type complies with the requirements in JAR 25.1419 *"Ice Protection"*.

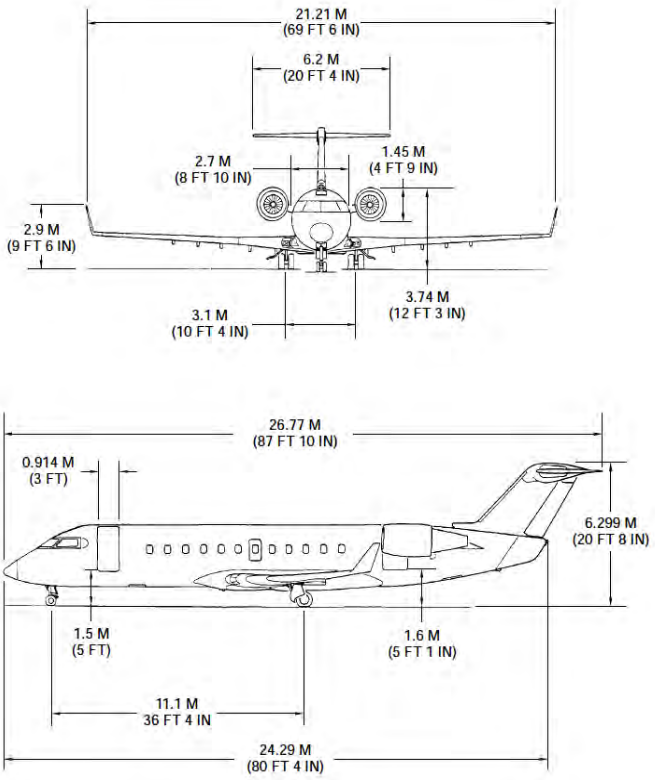


Figure 2: Dimensions.

1.6.2.2 *Flight controls*

The aircraft has conventional flight controls with mechanical transmission from the dual pilot controls in the cockpit to hydraulic and/or electrically powered control surfaces.

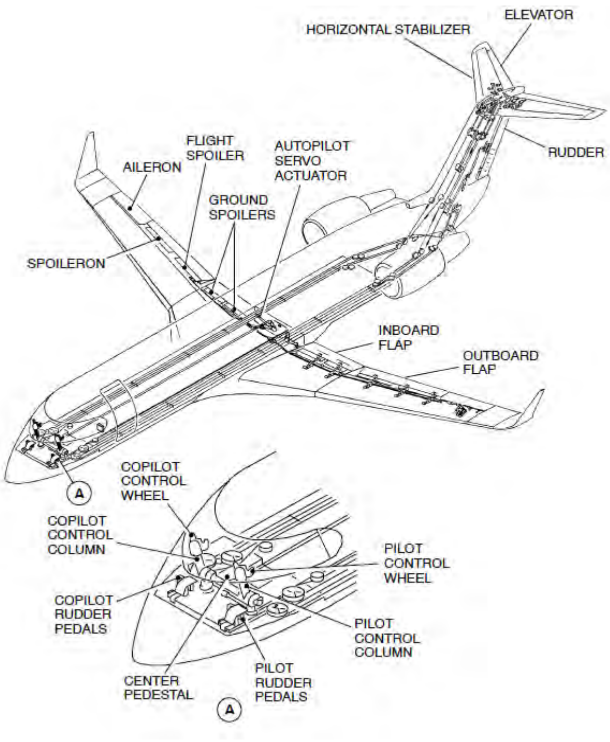


Figure 3: Flight controls.

1.6.2.3 *The wing's aerodynamic design*

The wing has conventional flaps on the trailing edge and a hard leading edge – meaning that there are no leading edge slats, slots or other aids to enhance flying characteristics at high angles of attack.

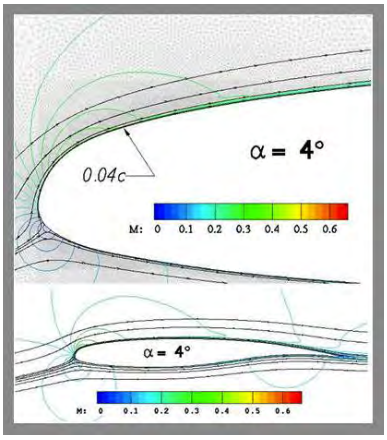
Bombardier refers to the wing profile as a ”Thin, high-speed aerofoil”. The profile's natural stalling characteristics when the angle of attack reaches a critical value, are that the airflow over the wing suddenly and without warning (like buffeting or vibrations), detaches from the leading edge of the wing and spreads rapidly backwards, causing the lift to be lost (so-called *leading edge stall*, see Figure 4).

The pattern of the stall spreading across the wing's planform must be said to be somewhat unconventional (both in relation to other swept wings and straight wings). On CRJ200, the stall will typically initiate in the ”break” marking the transition between the centre section and the outer wing panels. The loss of lift then spreads quickly across the outer wing panel. Even a minute roughness applied in this area has, according to the manufacturer, proven to reduce the stall angle substantially.

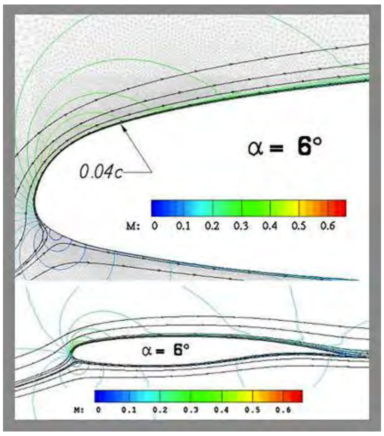
The stall characteristics of the wing have made it necessary to equip the aircraft with a stall protection system to comply with the certification requirements, see 1.6.2.4. During normal operations, the stall protection will activate well before the stall occurs.

Should a stall occur, one wing will normally stall before the other, causing the aircraft to roll. At the same time, a pitch moment can occur which raises the aircraft nose as a result of the loss of lift on the outer wing. As the angle of attack increases on the down-going wing (deepening the stall) and decreases on the up-going wing, the rolling tendency in an asymmetric stall will be increasing (auto-rotation). The remaining aileron effect is not sufficient to stop the rotation, and application of rudder will have a limited corrective effect (dihedral effect) as the low wing has stalled out. To regain control, the angle of attack must be reduced substantially so that the airflow can re-attach to the profile of the wing and the control surfaces can take effect. This requires adjusting the elevator to lower the nose, a manoeuvre which will most likely result in a loss of altitude.

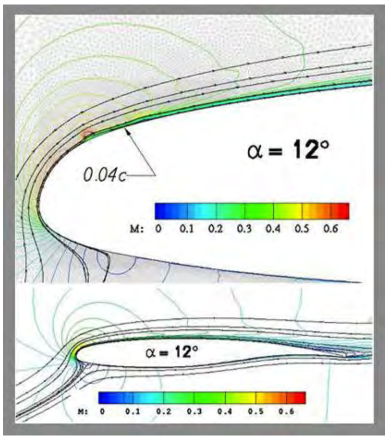
The following illustrations of how the airflow and pressure distribution over the wing profile change and stall occurs when the angle of attack (AOA) becomes critical, have been obtained from Bombardier's training material:



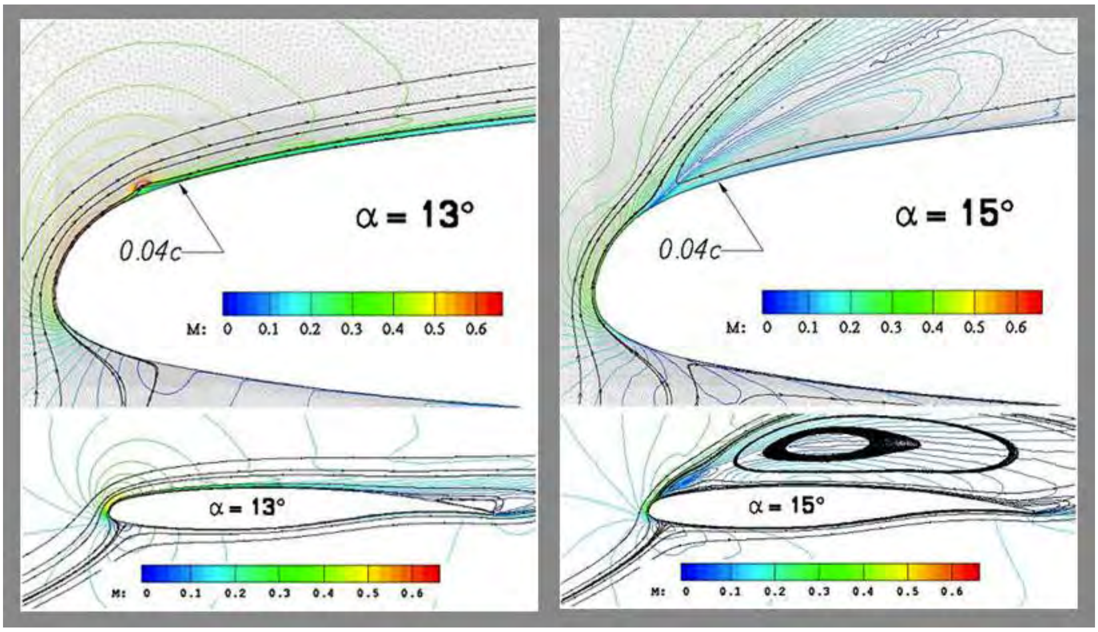
AOA = 4°



AOA = 6°



AOA = 12°
Visible bubble formation on the top of the leading edge



AOA = 13° *AOA = 15° "Leading Edge Airflow Separation"*

Figure 4: Airflow and pressure distribution during an increasing angle of attack until stalling occurs.

1.6.2.4 *Stall protection*

The stall characteristics for the wing entail that it will suddenly and without warning lose lift if the angle of attack becomes too high (see Figure 4). The aircraft has therefore been equipped with a stall protection system which warns the crew visually, with audio and through stick shaker when the angle of attack approaches the theoretical stall angle. Activation of stick shaker disconnects the autopilot. If the crew does not correct the aircraft's position, the stick is automatically pushed forward (stick pusher) to avoid stalling.

Sensors at the front of the aircraft fuselage measure the aircraft's angle of attack relative to the ambient airflow (AOA). This information is measured against airspeed, and the angles where the protection mechanisms activate are calculated in the Stall Protection Computer. If the angle of attack increases by more than one degree per second, the mechanisms will be triggered at a lower angle to prevent a stall before the protection mechanisms is able to react. The stick pusher activate three degrees earlier if the AOA increases by more than four degrees per second (phase advance). The stick shaker's phase advance is delayed for three seconds after weight-off-wheels.

Both pilots have a button (AP/SP DISC) on the control wheel which they can press and hold to stop the stick pusher. The pusher will deactivate automatically when the angle of attack has been sufficiently reduced.

The stall protection system seemed to be working as intended during the serious incident with OY-RJC. The stick pusher deactivation button was not used.

1.6.2.5 *The aerodynamic effect of environmental factors and contamination*

Contamination on the leading edge and upper wing, ground effect and crosswind are known factors of significance for the wing's ability to produce lift during take-off. The effect of these factors is described in further detail in 1.16. The wings of OY-RJC were inspected after the incident to rule out irregularities such as sealant protrusion. This could have been a contributing factor in a previous accident in Moscow (see 1.18.1). The wings on OY-RJC were without dents and irregularities which could have disturbed the airflow (Figure 5).

Figure 5: Right wing leading edge OY-RJC.

1.6.2.6 *The wing's anti-icing system and ice detection*

Bleed air from the engines' 14th compressor stage can be led through the wing leading edges as required to heat them and prevent build-up of ice both on the ground and in the air. The surface temperatures on the leading edges are in excess of 100 °C, and the system has almost immediate effect. According to the manufacturer, the Wing Anti-Ice (WAI) system is fully evaporative, and able to prevent all contamination from attaching to the wing leading edges.

The WAI system must be activated manually. When on, temperature sensors in the wing leading edges signal a control unit which automatically adjusts the bleed air valves as required.

The need for Wing Anti-Ice must be assessed after start (item on the After Start Checklist). The switch is located in overhead panel. If de-icing is required, one must wait until just before take-off to activate the system. The anti-icing fluid can otherwise be destroyed by the high temperature on the wing leading edge. The item ”Wing Anti-Ice” therefore reappears on the before take-off checklist. No warning is generated in the cockpit if this item is forgotten.

The aircraft has a system which detects ice during flight, but this system is neither designed nor suitable for detecting ice while the aircraft is on the ground.

1.6.2.7 *Amended airworthiness standards for ice protection (25.1419 Ice Protection)*

The provisions in force when CRJ200 received its type certification have now been amended. Both the current EASA CS-25 (which replaced JAR-25) and FAR 25 have been expanded with an item (e) in Section 25.1419 *”Ice Protection”* where the main rule is that the airframe ice protection system must activate automatically, or the flight crew must be alerted to activate it. However, operational procedures with the same purpose can still be used. An additional item (f) on the list establishes that the requirements in item (e) must apply for all flight phases unless the applicant for the type certification can prove that the use of anti-icing systems is not required in specific flight phases. The new rules have not been given retroactive effect.

In May 2010, EASA announced that they would look into new requirements relating to this. The new factor is that the type certification applicant must analyse the effect of a potential undiscovered wing contamination upon take-off and ensure that this is handled in a satisfactory manner, see 1.18.2.12.

1.6.2.8 *Relevant generic requirements related to systems safety*

CRJ200 was certified in accordance with design standards that contained generic systems safety requirements. The provisions in FAR-25 and JAR-25 are practically similar as regards equipment, systems and installations. These requirements also applied to anti-icing systems. The following excerpts from JAR 25.1309 illustrate some of the requirements:

> *–(a) The equipment, systems, and installations whose functioning is required by the JAR and national operating regulations must be designed to ensure that they perform their intended functions under any foreseeable operating conditions. ...*
>
> *(c) Warning information must be provided to alert the crew to unsafe system operating conditions, and to enable them to take appropriate corrective action. Systems, controls, and associated monitoring and warning means must be designed to minimise crew errors which could create additional hazards. ...*
>
> *(d) Compliance with the requirements of sub-paragraph (b) of this paragraph must be shown by analysis, and where necessary, by appropriate ground, flight, or simulator tests. The analysis must consider (see ACJ No. 1 to JAR 25.1309) –*
>
> *...*
>
> *(4) The crew warning cues, corrective action required, and the capability of detecting faults.”*

In other words, the provisions contained requirements for preparing analyses and, where necessary, conduct ground, flight, or simulator tests to demonstrate that the risk of systems failure is sufficiently low.

In type certification of complex aircraft such as CRJ200, the analyses to demonstrate compliance with 25.1309 can be very extensive. In order to limit this investigation, the AIBN has not reviewed these analyses.

1.6.2.9 *Examples of soft barriers being considered insufficient following lessons learned from accidents*

Takeoff configuration warning system is an example of how the aviation industry has introduced safety improvements following lessons learned from accidents. Originally, checklists and memory were depended on to ensure that crews did not initiate take-off without the aircraft being configured for safe take-off (e.g. related to flaps, slats, trim, spoilers, park brake, etc.). Following several major accidents, it was realised that such soft safety barriers were not sufficient to safeguard an aspect that was this critical to safety. This is especially the case as it has been demonstrated that crews can easily be distracted by other issues directly before take-off, making them forget this check. A requirement was therefore introduced for a take-off configuration warning system (FAR 25.703, CS 25.703). This system will alert the crew automatically by using an audio signal if take-off is initiated without the aircraft being correctly configured. The purpose is that the system should function as backup for the checklist, as there may be situations where the checklist review is interrupted or the take-off delayed (see preface to Amendment 25-42).

1.6.2.10 *Operational guidelines and procedures for wet and contaminated runways*

The manufacturer's approved Airplane Flight Manual (AFM) has a separate supplement concerning operation on wet and contaminated runways (Chapter 07 Section 03). It states when a runway is considered to be contaminated:

> *"A runway is considered to be contaminated, when more that 25% of the runway surface area (whether in isolated areas or not), within the required length and width being used, is covered by more than 3 millimetres (1/8 inch) of standing water or slush, or by loose snow, equivalent to more than 3 millimetres (1/8 inch) of water."*

A selection of applicable limitations follows:

- For take-off, the maximum permitted depth of slush contamination is 12.7 mm (1/2 inch), while 25.4 mm (1 inch) of wet snow is permitted.
- The maximum permitted crosswind component for take-off and landing on contaminated runways is 10 kt.
- The maximum permitted crosswind component for take-off and landing on wet runways with up to 3 mm reported water depth is 15 kt. The same limitation applies with a medium friction coefficient.
- Application of 8° flaps for take-off from contaminated runways is not permitted.
- Use of thrust reversers must be avoided when taxiing on a contaminated surface, except when necessary for safety reasons.

The reason for the latter limitation is that the wing can become contaminated (Operations Limitations page 02-04-3):

–To prevent wing contamination from reverse jet blast, operating the thrust reversers during taxi operations on wet and contaminated surfaces should be avoided."

The Flight Crew Operating Manual (FCOM) contains supplements with procedures for both cold-weather operations and operation on contaminated runways.

The following caution can be found in the cold weather procedures in Chapter D, *Taxi out*:

CAUTION

1. When the depth of contaminants on the runway surface exceeds the published runway contaminant depths in the Performance section of the Airplane Flight Manual (refer to the Airplane Flight Manual, CSP A-012, Chapter 6 - PERFORMANCE).
2. During extreme weather conditions (i.e. freezing rain).
3. When braking action is reported to be poor.
4. When crosswind component exceeds 15 knots and the runway is slippery.

Chapter E, *Take-off*, opens with a caution where it is mentioned that spray from the nose wheel can be a source of wing contamination:

CAUTION

1. Operating on ramps or taxiways which are contaminated with surface snow, slush or standing water when the OAT is 5˚C (41˚F) or below, can cause the wing leading edge to become contaminated with ice, e.g., from nose wheel splashing or jet blast spray. Just prior to take-off, select the wing anti-ice system ON and advance the thrust levers, as required, until the L WING A/ICE and R WING A/ICE caution messages are extinguished, to remove any leading edge ice contamination that may have accumulated during taxi.
2. The same procedure should be performed whenever the PIC has any doubt of the cleanliness of the wing leading edge prior to take-off.

1.7 Meteorological information

1.7.1 <u>General</u>

The Norwegian Meteorological Institute (DNMI) has prepared a report on the weather situation at Oslo Airport on the afternoon in question. A powerful low pressure north of Scotland moved south-east into the southern North Sea. Fronts with associated weather systems came in over Eastern Norway from the south-west. This resulted in heavy winds from the south, with storm-force winds along the coast and gales at several locations inland. The weather front did not pass Gardermoen, and the airport was, as shown by the maps below, in the warm zone of the low pressure throughout the period in question:

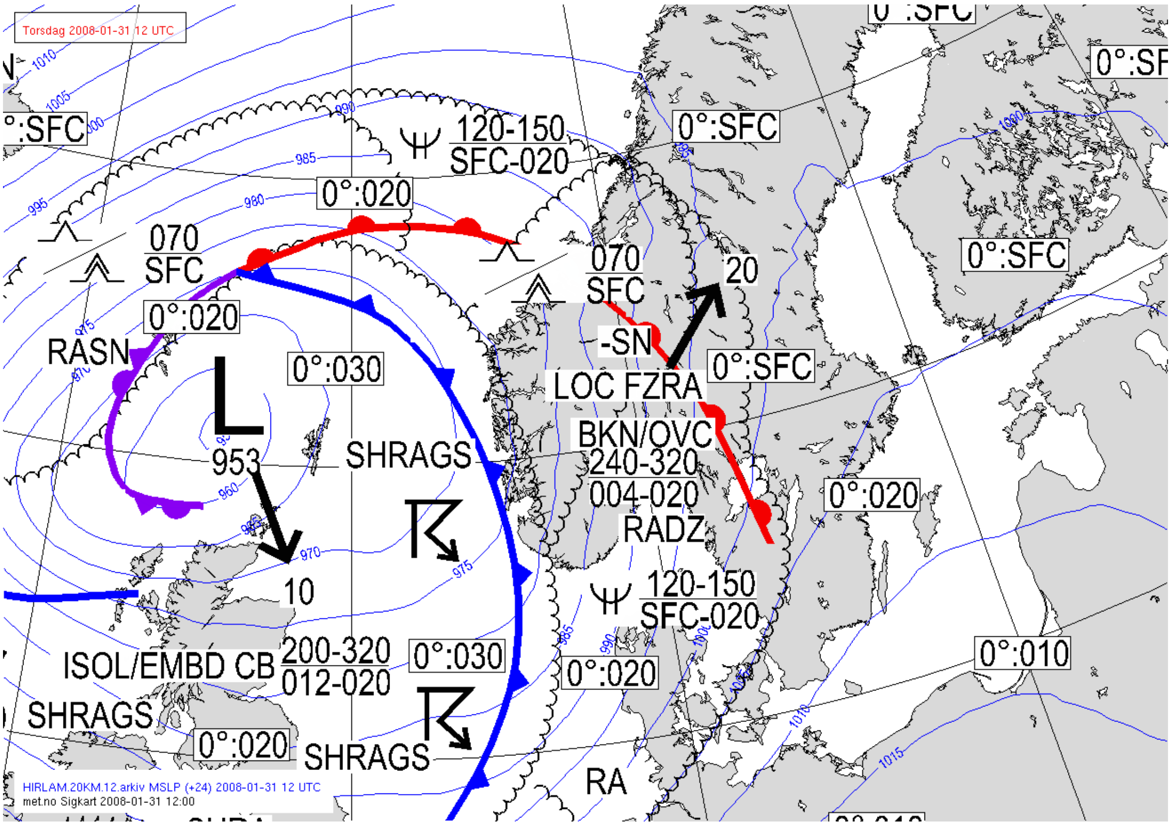


Figure 6: Significant weather chart valid 31-1-2008 12UTC (the incident took place at 1621UTC).

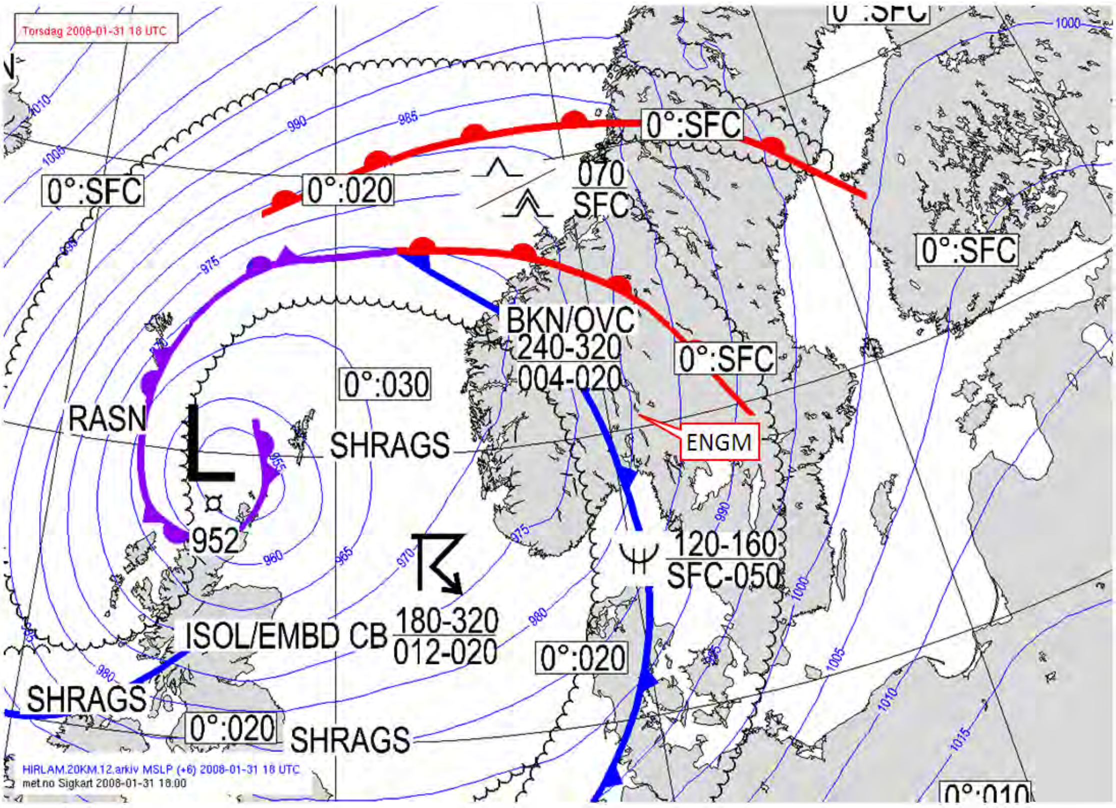


Figure 7: Significant weather chart valid 31-1-2008 18UTC (the incident took place at 1621UTC).

1.7.2 Observed and forecasted weather

1.7.2.1 The following METARs with TREND (routine weather observations with forecast for aviation purposes expressed in meteorological code) were issued for Gardermoen (ENGM):

1443UTC 15015G25KT 1400 1200NE R19R/P1500N R01R/P1500N RASN FEW005 BKN007 OVC011 00/00 Q0985 TEMPO 16020G30KT 1800 SNRA BKN004=

1521UTC 15018KT 1600 RASN FEW004 SCT007 BKN009 00/00 Q0983 TEMPO 16020G30KT 1200 SNRA BKN004=

1540UTC 15017KT 1300 R19R/P1500N R01R/P1500D RASN FEW004 SCT007 BKN009 00/00 Q0982 TEMPO 16020G30KT 1600 RASN BKN004=

1610UTC 15015KT 1700 SNRA SCT003 BKN006 OVC009 00/00 Q0981 TEMPO 16015G25KT 1200 RASN BKN004=

1640UTC 15015KT 1700 SNRA FEW004 SCT006 BKN008 00/00 Q0980 TEMPO 16015G25KT 1200 RASN BKN004=

1.7.2.2 The following weather forecasts (TAF, Terminal Aerodrome Forecast) were issued:

ENGM 311100UTC 311221 17015KT 5000 -RASN SCT005 BKN010 TEMPO 1215 17020G30KT 2500 SNRA BKN005 TEMPO 1521 17020G35KT 1200 SN BR VV004=

ENGM 311400UTC 311524 17020KT 4000 -RASN SCT005 BKN010 TEMPO 1521 17025G35KT 1200 SN BR VV004=

1.7.2.3 During the period in which OY-RJC was in the area, mostly south-south-east winds were observed and forecast, with strength of 15-20 kt with occational gusts up to 25-35 kt. The precipitation was a mix of rain and snow with moderate intensity. The temperature and dew point were both 0 °C. No freezing precipitation had been observed nor forecast on the afternoon in question. The Norwegian Meteorological Institute has provided the following overview of observations:

Table 4: A selection of weather observations

Time (UTC)	**Visibility (m)**	**Precipitation**	**Cloud base (ft)**
1350	1900	RASN	700
1420	1700	RASN	900
1450	1400	RASN	700
1520	1600	RASN	900
1550	1300	RASN	900
1620	1700	SNRA	600
1650	1700	SNRA	800
1720	1600	SNRA	800
1750	1800	SNRA	800
1820	1200	SNRA	800
1850	1900	SNRA	600

1.7.3 Radar images of precipitation

1.7.3.1 Below are radar images with indication of precipitation type and intensity at 1600UTC and 1615UTC. Blue is snow, red is rain and green is a mix of the two.

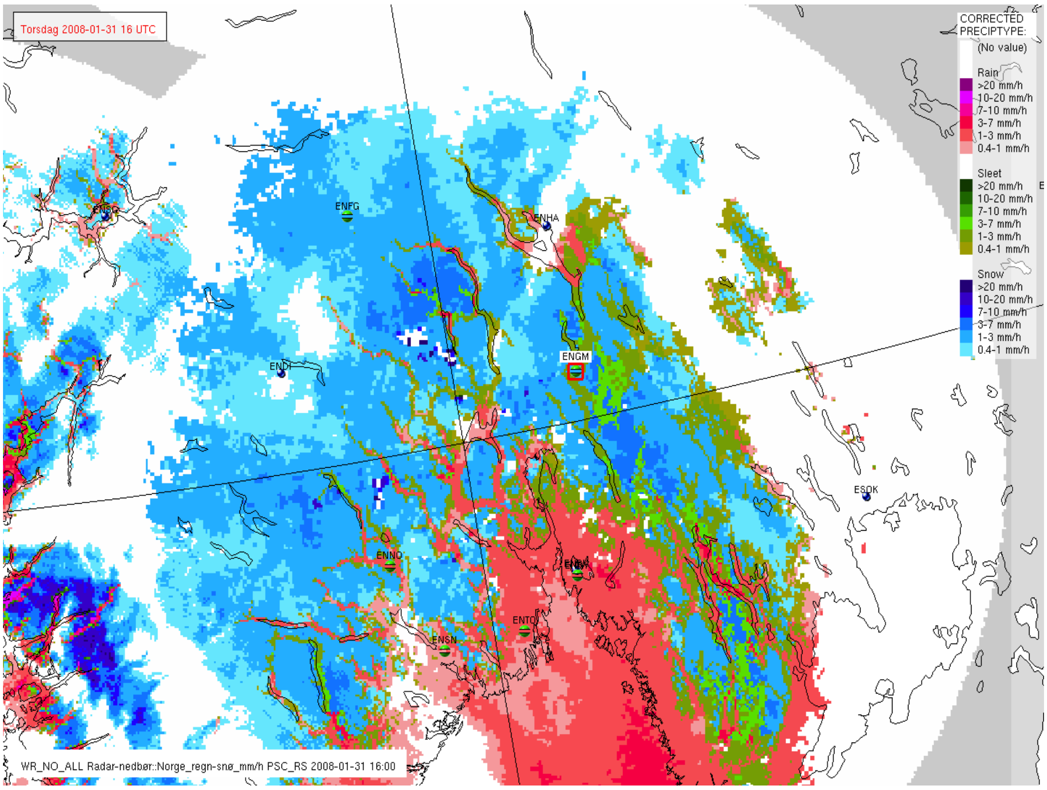


Figure 8: Radar image with indication of precipitation type and intensity at 1600UTC.

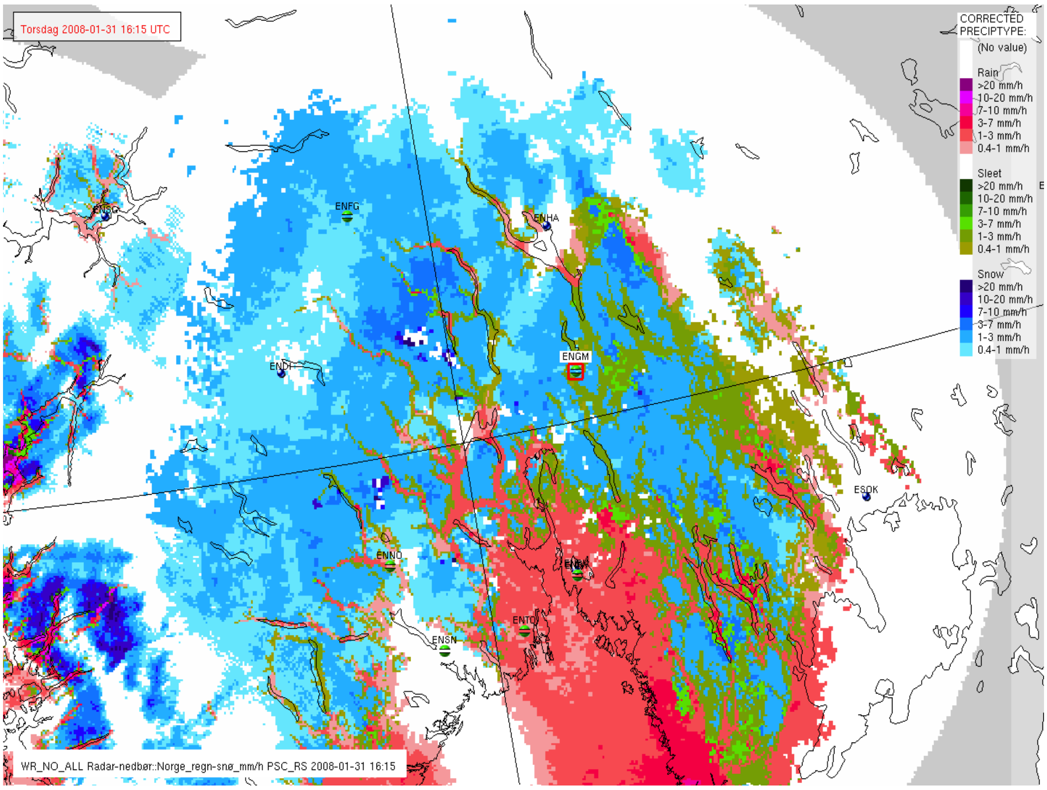


Figure 9: Radar image with indication of precipitation type and intensity at 1615UTC.

1.7.3.2 The report from the Meteorological Institute says the following about the precipitation:

> *"At Norwegian weather stations, the precipitation is measured twice a day, at 06Z and 18Z. The measurements from Gardermoen show that 12 mm of precipitation fell between 06Z and 18Z on 31 January. A rule of thumb says that 1 mm of precipitation corresponds to 1 cm of dry snow. In this instance, the precipitation was wet, and the ratio becomes lower. It is reasonable to assume that 8-10 cm of wet snow fell during the day. Based on the observation material, it is likely that most of this precipitation fell between 14Z and18Z, when the precipitation was most severe. It cannot be excluded that for a short period of time (a few minutes) the precipitation may have been more than moderate without this being picked up in the observations."*

1.7.4 <u>Other observations</u>

1.7.4.1 Both the airport personnel on duty involved in de-icing operations and others who were outside on the day in question considered the weather to be unusually bad. Large, wet snowflakes flew through the air, sticking to everything before melting. None of the witnesses contacted by the Accident Investigation Board has reported freezing precipitation.

1.7.5 <u>Guidelines for observation of visibility in precipitation</u>

1.7.5.1 Weather observations at Gardermoen are made by personnel from Oslo Airport's technical operating centre. The same persons administrate aircraft parking. As part of the shift rotation scheme, the personnel are assigned special MetObs duties. An automatic observation system (Vaisala) proposes METAR on the basis of recorded values. The personnel's task is to correct errors and distribute the METAR to the Norwegian Meteorological Institute at Blinderen in Oslo, so that the institute can add a forecast (TREND) to the observations. The criteria for assessment of precipitation intensity are related to visibility, and the following guidelines have been given: (+ is used about strong, heavy or well-developed, while - is used about weak or light)

Table 5: Norwegian guidelines for assessment of precipitation intensity based on visibility

VEILEDENDE RETNINGSLINJER

SAMMENHENG MELLOM NEDBØRINTENSITET OG SIKTVERDIER TIL BRUK I FORHOLD TIL METAR OG TAF

VÆR	SIKT
-RA	VVVV > 20 KM
RA	4 KM < VVVV ≤ 20 KM
+RA	VVVV ≤ 4 KM
-DZ	VVVV > 4000 M
DZ	1000 M < VVVV ≤ 4000 M
+DZ	VVVV < 1000 M
-SN	VVVV > 2000 M
SN	500 M < VVVV ≤ 2000 M
+SN	VVVV ≤ 500 M

For sludd, andre blandinger av nedbørsformer eller f.eks snøfall og tåkedis, er det vanskelig å sette noen entydige sammenhenger mellom intensitet og sikt. For sludd som inneholder mest snø bør en la reglene som gjelder for snø være et utgangspunkt.

For tåke og dis skal ikke + eller – nyttes.

1.7.5.2 During the investigation, the Accident Investigation Board became aware of a report on from the US National Centre for Atmospheric Research (NCAR) - *"How Snow Can Fool Pilots"*. The report addresses the problem of the established intensity degrees for precipitation being based on visibility values, while the factor of importance for Hold-Over Time is water content. In darkness, the inaccuracy may be even greater than in daylight.

1.7.5.3 The AIBN presented the relevant weather observations from Gardermoen to one of the authors of the NCAR report, Roy Rasmussen. He concluded that the precipitation intensity could have been about 30 g/dm^2/hour, i.e. heavy, in spite of visibility being as good as 1300 - 1700 m. This is due to high density per snowflake (wet, aggregated snow crystals) and that each flake develops a high terminal velocity. Rasmussen also referred to the article *"The Estimation of Snowfall Rate Using Visibility*" published in the Journal of Applied Meteorology in 1998. A summary of this article follows in Appendix G.

1.7.5.4 In the USA and Canada, a study was conducted in 2002/2003 of Hold-Over Times (HOT, see 1.10.3.3). The countries had different tables for assessment of visibility values, resulting in differing HOTs. Harmonised guidelines were prepared. The new, North American guidelines for assessing precipitation intensity when snowing are printed in Table 6. A footnote to the table shows that the guidelines were in part based on the above-mentioned research report:

Table 6: North American guidelines for assessing precipitation intensity based on visibility

1 Base
Cent
Usin

1.7.5.5 The Norwegian Meteorological Institute informs the Accident Investigation Board that the values in Table 5 are meant as guidelines, and that visibility during precipitation is often reduced by the precipitation itself and by mist and fog. The observer must take this into account when determining precipitation intensity. If one were to use visibility as the only parameter when determining precipitation intensity, the Norwegian Meteorological Institute believes that the assessed intensity would in most cases be too heavy.

1.8 Aids to navigation

Not applicable.

1.9 Communication

Nothing abnormal reported.

1.10 Aerodrome information and aids

1.10.1 <u>General</u>

1.10.1.1 Oslo Airport Gardermoen (ENGM) is Norway's main airport and has two parallel runways. The airport is located 19 nm north-north-east of central Oslo, 681 ft above mean sea level. A map of the airport has been included as Appendix B.

Physical characteristics runway 19L:

Magnetic direction:	195°
Dimensions:	2950 m × 45 m
Runway surface:	Asphalt/concrete (300 m segments immediately inside each threshold)

TORA/ASDA: 2950 m

1.10.2 Runway status

1.10.2.1 The log from the aerodrome maintenance service at Oslo Airport shows that the relevant runway (eastern runway) was closed for snow clearing and sanding between 1637 and 1648 hours and between 1730 and 1743 hours. Continuous snow clearing was underway on the two runways in alternate turns. OY-RJC took off at 1720 hours, approx. 30 minutes after the runway had been cleared of snow. After the incident take-off and before the next snow clearing at 1730 hrs, two airliners landed.

1.10.2.2 The runway report after snow clearing at 1648 shows that there was some slush on the runway. The average depth was stated to be 3 mm, the minimum depth (first reporting level) which must be reported if there are traces of slush on the runway. Friction measurements along a third of the runway showed 0.42, 0.38 and 0.36, respectively, which corresponds to "medium".

1.10.2.3 The runway report after snow clearing at 1743 shows that there was wet snow/ice on the runway. Supervisory personnel have stated that ice only occurred in wheel ruts where the snow had been compacted. The average depth was stated to be 6 mm, the minimum depth (first reporting level) which must be reported if there is wet snow on the runway. Friction measurements along a third of the runway showed 0.43, 0.39 and 0.36 respectively (medium).

1.10.2.4 The airport must close the runway when the slush depth exceeds 13 mm (closing criteria in accordance with OSL manual for LHT/Aerodrome maintenance service). For wet snow, the closing criterion is 25 mm. These depths correspond to the maximum permitted depths for take-off with CRJ200 (½ inch slush, 1 inch wet snow).

1.10.2.5 The supervisory airport personnel have stated that the depth did not exceed the closing criteria when the snow clearing started after OY-RJC's take-off. The Norwegian Meteorological Institute has estimated the depth to be 1-2 cm of slush/wet snow based on the recorded precipitation intensity in the radar images being 3 - 7 mm/hour in the 30-40 minutes that passed from snow clearing took place to take-off.

1.10.2.6 There are three temperature sensors on the runway. At the north end of the runway, where the take-off started, the recorded surface temperature was -1.2 °C when OY-RJC took off. In the middle of the runway length, the surface temperature at the same time was recorded as -0.3 °C, while it was -1.2 °C in the southern end. The temperature is also recorded 10 cm into the ground. Values there varied between -1.4 and -1.9 °C.

1.10.2.7 Chemicals to prevent icing had been used on the eastern runway system on the morning in question and the preceding day[3]. The airport uses Aviform L50 for this purpose. Logged deployment on the runway was 2492 and 4056 litres respectively. Taxiways were also treated, but chemicals had not been used in the central tarmac area since 29 January.

[3] *It has later been indicated that chemicals used on the ground may have a negative effect on the effect of anti-icing fluid used on aircraft, cf. EASA Service Information Bulletin SIB No. 2010-26 (EASA-SIB-2010-26-R1t.pdf).*

1.10.2.8 The following day also saw heavy snowfall at Gardermoen, and an airliner had a runway excursion when taxiing in after landing. The main airport was then closed for several hours due to operating problems for important snow clearing machinery and insufficient snow clearing capacity.

1.10.3 De-icing

1.10.3.1 Oslo Airport has established a de-icing area near the runway thresholds. On the afternoon in question, runway 19L was in use for take-offs, and de-icing took place on platform B-North. The airport has a separate communication frequency for de-icing coordination, and the traffic is monitored with a ground tracking radar. In addition, the de-icing platform is monitored by cameras (see Figure 10).

1.10.3.2 The airport has two operators involved in de-icing. SAS Ground Services Norway AS (SGS) is the largest operator, and supplied the service to Cimber Air. The de-icing vehicles used are modern and have computer-controlled monitoring of fluid temperatures, fluid consumption and time spent. De-icing and anti-icing take place in accordance with the current edition of *"Recommendations for De-icing / Anti-icing of Aircraft on the Ground",* published by the Association of European Airlines (AEA). Some airlines have specified special requirements in addition. Cimber Air had no special requirements beyond the general requirements when the incident took place.

1.10.3.3 SGS used Type II anti-icing fluid (Clariant Safewing MP II, see Appendix C). Anti-icing fluids are subject to rigorous requirements, and the fluid type in question has been tested and approved in line with applicable specifications. The estimate for how long the fluid protects the surface of the wing against ice forming in precipitation, so-called Hold-Over Time (HOT), and flow-off performance during take-off run are especially important factors. The fluid's viscosity changes so that it begins to flow off the wing when the air velocity reaches about 30 kt. At more than 80 kt, most of the fluid will have flowed off. The certification requirements for aircraft permit a thin layer of de-icing fluid residue.

1.10.3.4 On Gardermoen, the relevant type of fluid was put to use in the winter season 2007/2008. SGS had received only positive feedback in that regard. The new fluid type had a longer HOT than the type II fluid used earlier.

1.10.3.5 The Accident Investigation Board also contacted Clariant, the manufacturer and supplier of the fluid. They were familiar with the de-icing systems at Oslo Airport, and stated that the facilities, equipment, personnel and all stages of the process held a high standard. The crew on OY-RJC and other pilots contacted by the Accident Investigation Board have stated that the de-icing services at Oslo Airport appear very professional.

1.10.3.6 The AIBN interviewed the de-icing personnel at SAS Ground Services who de-iced OY-RJC. They stated that 31 January had been a hectic working day with poor weather and a lot of wind, but that the work went ok in spite of the traffic direction on B-North having been turned around. Usually, the traffic direction in the de-icing area corresponds to the taxiing direction to make the de-icing process run as smoothly as possible. In strong winds, however the aircraft are taxied in from the opposite end and positioned into the wind in order to make the treatment possible.

1.10.3.7 Registrations show that a total of 234 aircraft were de-iced that day, and that 13 de-icing vehicles were in use. The treatment took place in four parallel tracks, following set routines. The aircraft type CRJ200 is considered uncomplicated in a de-icing context. It is small, with low wings and rear fuselage mounted engines, well away from wings and tail surfaces which is to be treated.

Figure 10: Video image from the de-icing platform as OY-RJC taxies in for treatment.

1.10.3.8 OY-RJC taxied in for de-icing at 1703 hours. The wings and tail section were treated in two steps in parallel from two vehicles, one on each side of the aircraft. The first step was de-icing with hot water spray. The aircraft's flaps setting was then 45°. Treatment started at 1704 hours. Registrations show that a total of 708 litres of water were used. The Final Release Person (FRP) has explained that he, as usual, walked along the wing leading edge from tip to root feeling with a bare hand to check that the surface of the wing and leading edge was free of ice before the next step started. The operators in the special vehicles checked visually up close that the tail surfaces were clean.

1.10.3.9 FRP informed the commander that the first step had been completed. The flaps were then raised to 20° before the application of the anti-icing fluid started. The various flaps settings are in accordance with the manufacturer's recommendations. Registrations show that the final treatment with application of 100% type II anti-icing fluid commenced at 1706 hours and that a total of 104 litres of fluid were used. The wings were treated before the tail. The entire process had been completed at 1711 hours.

1.10.3.10 Guidelines for HOT in various weather conditions and temperatures, *"Guidelines for Holdover times Clariant Safewing MP II FLIGHT type II Fluid Mixtures as a Function of Weather Conditions and OAT",* is included in Appendix C. 100% fluid concentration, outdoor temperatures exceeding -3 °C and snowy weather indicate a HOT between 1:00-1:35. The shortest stated time is for moderate snowfall, while the longest time is for light snowfall. No guidelines are given for heavy snowfall, freezing rain, hail, snow or ice pellets. The common practice is that the airlines have procedures which do not permit flying in such conditions. The table contains a warning to the effect that the protection time will be shorter in ”heavy weather conditions”:

> *”[…] Heavy precipitation rates or high moisture content, high wind velocity, or jet blast may reduce holdover time below the lowest time stated in the range…”*

1.10.3.11 Clariant has stated that more than $25g/dm^2$/hour (corresponds to 2.5 mm water/hour) is considered ”heavy snow”. It is not specifically stated what constitutes high wind velocity, but the wind conditions in the period in question (15-20 kt) were below the critical value. Bombardier's own expert was shown a video of the de-icing and also evaluated the available information from the relevant process. He concluded that the wing most likely was protected by anti-icing fluid as the take-off started only 15 minutes after application.

1.11 Flight recorders

1.11.1 OY-RJC was equipped with voice and flight recorders in accordance with applicable regulations. The relevant part of the voice recording had been erased during the remainder of the flight, as the recording duration is limited to 30 minutes. The flight recorder, an L3 model F1000 „solid state" digital flight data recorder, was transported to the UK Air Accidents Investigation Branch (AAIB) at Farnborough in England for download. 62 hours of good-quality data were recorded and downloaded. The data file was sent to the Transportation Safety Board in Canada for further analysis. The results have been discussed in 1.1.16, and a selection of parameters is shown in Appendix D.

1.11.2 The 62 hours with data were from 41 flights. In addition to the incident in question, it turned out that the stick shaker had activated in an additional four take-offs due to the elevator being neutralised too late. The rotation rate was not critical in any of these take-offs. The problem according to Bombardier seems to be *”[...] that in each event the pilot held the take-off rotation in an attempt to obtain the target pitch attitude immediately on take-off rotation, rather than rotating towards it and maintaining the all-engine take-off safety speed V2 +10 knots as stated in the Flight Crew Operating Manual (FCOM)”*.

1.11.3 Bombardier considered the findings to be alarming, and contact was immediately established between the manufacturer and the management of Cimber Air. Cimber Air then briefed its pilots about the serious incident at Gardermoen and emphasised the importance of correct take-off technique. Bombardier issued information about the incident to all operators in the form of All Operators Message no. 1099, dated 13 February 2008.

1.11.4 To obtain a basis for comparison, data from the flight recorder on another of the operator's aircraft of the same type with registration OY-RJA was downloaded and analysed by TSB. This DFDR contained 64 hours of data from 48 flights. The registration took place at the end of February, after the serious incident with OY-RJC had been made known to the pilots. The maximum observed rotation rate was 3.0°/sec. The average rotation rate for those 48 departures was 2.05°/sec.

1.12 Wreckage and impact information

Not applicable.

1.13 Medical and pathological information

Not applicable.

1.14 Fire

Not applicable.

1.15 Survival aspects

Not applicable.

1.16 Tests and research

1.16.1 The manufacturer Bombardier analysed flight recorder data from the incident involving OY-RJC and concluded that stalling occurred at approximately the same time as the stick shaker activated, at an angle of attack of about 5 degrees lower than expected in free air. Bombardier's calculations show that the aerodynamic effect as a result of crosswind and ground effect would result in the stall occurring approximately two degrees earlier. The manufacturer explained the remaining three degrees with contamination on the wing leading edge.

1.16.2 The AIBN wanted to clarify the following questions:

1. *What contaminated the wing leading edge, and how did the wing leading edge/wing become contaminated?*

2. *Can other factors than the pilot's stick movement have contributed to an excessive rotation rate?*

1.16.3 To answer the AIBN‟s questions, Bombardier conducted a simulation analysis with the relevant DFDR data. They prepared the following graphical presentation of the lift coefficient versus angle of attack during the relevant departure with OY-RJC:

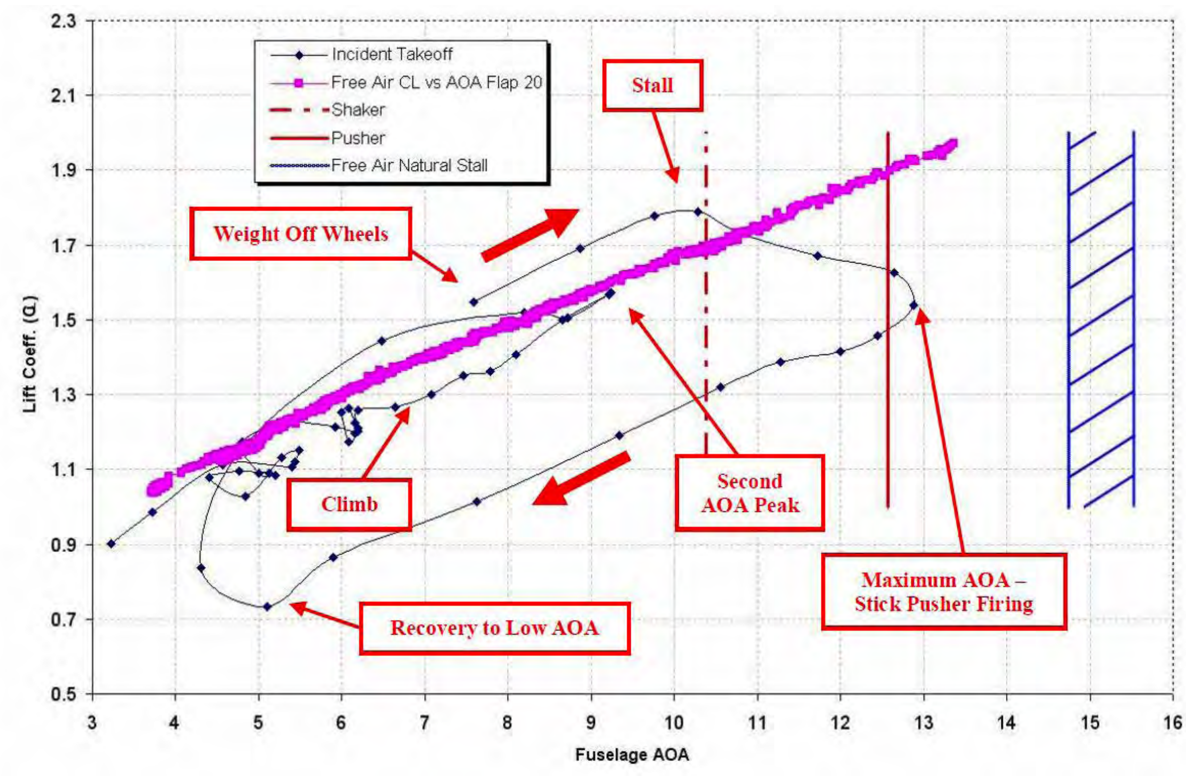


Figure 11: The lift coefficient versus angle of attack during the take-off in question (C_L-alpha)

1.16.4 In the statement following the C_L-alpha figure above, Bombardier writes the following:

> *"The analysis and simulation matching also showed that there was a general lift loss that occurred through most of the rotation and initial climb. Inspection of the $C_L$alpha curve, […], and the simulation analysis […], shows that, compared with normal take-off data, the lift curve from the incident aircraft falls below the expected values immediately after WOW and also following recovery from the stall as the aircraft climbed out of ground effect (in the climb the $C_L$alpha curve did not fully revert to the certification standard –free air" curve). This may indicate that, not only did the aircraft stall at a lower than expected AOA, there was also a general (and more symmetrical) loss of lift at all AOA throughout the take-off phase of flight. This lift loss was essentially symmetrical; the wings remained essentially level during these phases of flight with little aileron control input."*

1.16.5 For the simulation to conform with observed data, it was also necessary to introduce a *"nose down pitching moment"* in the model just after take-off. According to Bombardier, this indicates that the symmetric loss of lift occurred over the inboard wing:

> *–The simulation match indicates that this symmetrical loss of lift was most likely confined to the inboard wing because this would cause an aerodynamic nose down moment as required by the model."*

1.16.6 In its response, Bombardier pointed out to the AIBN that the aircraft type has operated from contaminated runways for many years without this creating problems:

"The CRJ-200 has been in-service since 1992 and operations from contaminated runways have occurred many times. During this time Bombardier has not received any reports of unusual aircraft behaviour or loss of lift concerning take-off operations from contaminated runways.

Normally, take-off from contaminated runways is conducted with the wing anti-ice system ON. The wing leading edge anti-ice system operates at a high temperature and is a fully evaporative anti-icing system (surface temperatures in excess of 100° C). During take-off with the engines operating at high power there is adequate engine bleed air to keep the wing at high temperature to prevent any contamination from adhering."

1.16.7 Based on the manufacturer's warnings that spray from the nose wheel can contaminate the wing during taxiing on contaminated surfaces (see 1.6.2.7), the AIBN asked Bombardier to provide pictures and comment on the aerodynamic effect when a take-off is made from a contaminated runway (Figure 12). The AIBN received a number of scanned photographs from a "Water Ingestion Test"[4] on the relevant aircraft type in 1991. The pictures show that the water spray from the nose wheel hits the wing leading edge and the surface of the wing from the wing root and as far out as the „break" on the leading edge when the aircraft accelerates up to take-off speed with various flaps settings in water depth of approx. ¾ inches (1.9 cm). The spray pattern was similar for all measured speeds (50-120 kt).

Figure 12: Photo from the Water Ingestion Test. Note that the spray from the nose wheel will hit the wing leading edge and the surface and underside of the wing in the area where stall is normally initiated.

1.16.8 The comments from Bombardier:

"Water trough tests [...] have shown that spray from the nose wheel can envelop the inboard wing, as far outboard as the wing break (WS 148). Stall tests of the CRJ-200 with wool tufts applied to the wing upper surface

[4] *One of the airworthiness requirements for aircraft in the transport category is that the aircraft must be designed to avoid substantial amounts of water or slush spray from the surface from hitting the engine air intake (FAR 25.1091 (d) (2), EASA CS 25.1091 (d) (2)). That the requirement has been met is demonstrated and documented through the Water Ingestion Test. The tests include accelerating the airplane up to take-off speed with different flaps settings in water approx. ¾ inches (1.9 cm) deep*

showed that the stall initiates at the wing break and spreads outboard. Minor modifications made to the geometry of the wing leading edge at the wing break were shown to have a significant effect on the AOA for stall."

1.16.9 The AIBN also wanted to clarify whether the slush layer on the runway could, in any way, have contributed to the rotation rate becoming excessively high, focusing on the fact that the layer increases the rolling resistance and therefore is a factor which contributes to forcing the nose wheel down until the wheel lifts from the ground - making a stronger elevator adjustment necessary to rotate the aircraft. The rotation rate may then, initially, become high, until the pilot can react and adjust the elevator setting. Bombardier's simulation showed no such effect could be measured. The elevator adjustment matched the expected and real change in pitch.

1.16.10 In this investigation, the AIBN has raised several issues with the manufacturer, for example whether contamination of the flaps leading edge or underside of the wing behind 7% MAC (Mean Aerodynamically Chord) may have been a factor. Bombardier has substantiated why contamination of the underside of the wing can be excluded as having had a significant effect on the stall, but has later admitted that ice contamination of the flaps leading edge may have disturbed the flow of air over the flaps, causing a loss of lift. This is seen in connection with the use of hot water for de-icing. The leading edge of the flaps is exposed to hot water when the flaps is down all the way, but is covered when the flaps are set at 20° prior to application of anti-icing fluid (see 1.10.3.8). Bombardier has stated that a discussion of whether the approved procedure is ideal in this regard was initiated at the end of 2010.

1.16.11 Bombardier has also referred to tests that have disproved that sand or other contamination can mix with the anti-icing fluid and disturb the airflow, preventing the fluid from collapsing and flowing off as intended. The manufacturer also rejected that contamination on the wing could have caused undesired pitch-up as a result of reduced stability, as the accident investigation board in the Commonwealth of Independent States, the Air Accident Investigation Commission, has indicated in its report on the air accident with a CL-600-2B19 in Moscow on 13 February 2007 (IAC Final report dated 13 July 2008, p. 47).

1.16.12 An observed difference between the recorded position for the right and left elevator splits during the take-off rotation (Appendix D) was also raised with the manufacturer. The operator had not registered anything out of the ordinary with the elevator prior to the incident, and no unscheduled maintenance work had taken place in the relevant area. Bombardier could explain diverging values with the system's design and the applied sampling method. Average values were applied in the simulation.

1.17 Organisation and management

1.17.1 <u>The Clean Aircraft Concept</u>

1.17.1.1 The lift generated by any wing will be influenced by any contamination on the surface. The aviation regulations prohibit take-off with frost, ice or snow on the aircraft's critical surfaces. Operators must have procedures for de-icing, anti-icing and inspection, and the commander must not take off unless the requirements have been met, see EU OPS 1.345:

—Ice and other contaminants — ground procedures

(a) An operator shall establish procedures to be followed when ground de-icing and anti-icing and related inspections of the aeroplane(s) are necessary.

(b) A commander shall not commence take-off unless the external surfaces are clear of any deposit which might adversely affect the performance and/or controllability of the aeroplane except as permitted in the Aeroplane Flight Manual."

1.17.1.2 The Canadian aviation authority has described "The Clean Aircraft Concept" in Airworthiness Notice – B017. The notice mentions the effect of contamination on critical surfaces, various types of contamination and methods to remove them, the problem of cold-soaked wings, various de-icing and anti-icing fluids, Hold-Over Time, etc. The following text excerpt is from that document:

"Test data indicate that frost, ice or snow formations having a thickness and surface roughness similar to medium or coarse sandpaper, on the leading edge and upper surface of a wing, can reduce wing lift by as much as 30% and increase drag by 40%. Even small amounts of contamination such as this have caused and continue to cause aircraft accidents, which result in substantial damage and loss of life. A significant part of the loss of lift can be attributed to leading edge contamination. The changes in lift and drag significantly increase stall speed, reduce controllability and alter aircraft flight characteristics. Thicker or rougher frozen contaminants can have increasing effects on lift, drag, stall speed, stability and control."

1.17.2 Cimber Air

1.17.2.1 In January 2008, Cimber Air operated the aircraft types ATR 42, ATR 72 and CRJ200. The route network was mainly between various destinations in Denmark and some cities in Sweden, Norway and other Northern European countries. In connection with SAS' decision to discontinue its flights with the aircraft type Bombardier DHC-8-400, Cimber Air received a contract on flights for SAS for a period.

1.17.2.2 Cimber Air expanded its route network even more in the autumn 2008. During the same year, Cimber acquired the bankrupt operator Sterling, which operated Boeing 737s. The operator changed its name to Cimber Sterling in 2009.

1.18 Other information

1.18.1 Previous accidents and incidents

The AIBN has recorded the following accidents and incidents where aircraft in the CL-600 series have lost control in connection with take-off or discontinued landing in winter conditions:

Table 7: Previous accidents and incidents

Date & reference	Place	Model	Flight phase	Weather conditions, course of events, damage
1997	Bombardier Test flight Canada	CL-600-2B19	Take-off	Take-off from contaminated runway, no precipitation, no active frost. Temp. -3 °C. Wing Anti-Ice (WAI) OFF. Rotated 5 kt early, with pitch rate 6-7°/sec. Stalled before stick shaker, control regained. Observed globules of ice at the wing root extending out to leading edge 'break' - assumed to stem from the reversal test that took place during taxiing or from nose wheel spray. Resulted in changes to AFM.
16 Dec. 1997 TSB Rep. A97H0011	Fredericton Airport, New Brunswick, Canada	CL-600-2B19	Go-around	Icing conditions. Stalled 4.5 ° below the expected stall angle in a low energy go-around at low altitude. WAI OFF. The wingtip hit the ground. 42 people on board (p.o.b.), 9 seriously injured.
4 Jan. 2002 AAIB Rep. 5/2004	Birmingham International Airport, UK	CL-600-2B16	Take-off	Frost. Did not de-ice. WAI OFF. Stalled to the left, wingtip touched the ground, rolled inverted, fire, 5 p.o.b., all fatally injured. SPS did not work as intended.
21 Nov. 2004 CAAC-AS/AAR-2007001	Baotou Airport, Inner Mongolia, China	CL-600-2B19	Take-off	Stalled just after rotation, did not regain control. Impacted ground and caught fire. No precipitation, light fog, frost on the wings. WAI OFF. All 53 p.o.b. and two people on the ground fatally injured.
28 Nov. 2004 NTSB AAB-06/03	Montrose, Colorado, USA	CL-600-2A12	Take-off	Light snow, mist. Did not de-ice. WAI OFF. Uncontrolled roll first to the left, then to the right and then left again, wingtip hit the ground, fire. 6 p.o.b., 3 fatally and 3 seriously injured.
7 Mar. 2005 Operator's Report IIR0305	Ljubljana, Slovenia	CL-600-2B19	Take-off	Clear winter weather, moderate frost. The wings were probably contaminated with thickened anti-icing fluid applied the preceding evening. Uncontrolled roll to the left, regained control with 1 m ground clearance for the wingtip.
13 Feb. 2007 IAC	Vnukovo Airport, Moscow, Russia	CL-600-2B19	Take-off	Heavy snow. WAI OFF. Early rotation. Uncontrolled roll left-right, wingtip hit the ground, rolled inverted, caught fire, 3 p.o.b., all seriously injured.
26 Dec. 2007 IAC	Almaty Airport, Republic of Kazakhstan	CL-600-2B16	Take-off	Winter weather. Loss of control, aircraft impacted ground and caught fire. 4 p.o.b.,1 fatally injured. Report still not published by IAC.
31 Jan. 2008	Oslo Airport Gardermoen, Norway	CL-600-2B19	Take-off	Snowy weather, contaminated runway, WAI OFF, rotation rate 6.1°/sec. Uncontrolled roll to the right, stick shaker and stick pusher activated, control regained, lowest ground clearance for wingtip approx. 2.4 m. 4 p.o.b., no injuries.
14 Feb. 2008 IAC	Zvartnots Airport, Yerevan, Armenia	CL-600-2B19	Take-off	Winter weather, moist air, no precipitation, no frost or ice observed. WAI OFF. Maximum rotation rate 4.5°/sec. Uncontrolled roll, left wingtip hit the ground, rolled over, fire, 21 p.o.b., 7 seriously injured.

1.18.1.1 In addition, a CL-600-2B16 crashed during a test flight at Mid-Continent Airport, Wichita, Kansas, USA, on 10 October 2000. The weather played no part in that accident. The test entailed flying the aircraft with the centre of gravity placed too far aft. The pitch rate upon take-off was 9.6°/sec. The aircraft stalled suddenly, hit the ground with a wingtip, rolled over and caught fire. The three people on board died. The following quote from the NTSB's report looks at what a normal rotation rate is:

―The maximum rate of rotation achieved during the take-off at Wichita was established, by the NTSB, to be 9.6°/sec. Information held by the

manufacturer indicated that this was very high compared with the maximum observed in normal operations, of between 3.4 and 6.1°/sec, and higher even than the 7.5°/sec maximum rate achieved during Certification performance take-off testing." (NTSB Aircraft Accident Brief CHI0 MA006, p. 57).

1.18.1.2 Of the cases mentioned above, only the test flight in 1997 and the incident in Slovenia in 2005 have not been investigated by the national investigation authority where the accident or incident took place. A report has not yet been published for the accident in Kazakhstan. This means that there are two reports available from the US accident investigation board NTSB, one from the Canadian accident investigation board TSB, one from the UK Air Accidents Investigation Branch AAIB, one from the Chinese accident investigation board and two from the Russian accident investigation board IAC (see references). The investigation reports are relatively comprehensive, and issues that are relevant for the incident in Norway are described and discussed in detail. They include the following topics:

- Wing design and stalling characteristics
- Compliance with airworthiness standards
- Stall protection
- Anti-icing systems and ice detection and warning systems when on ground
- Effect of contamination on wing/wing leading edge
- Effect of the roughness of the contamination
- Rotation rate at take-off

1.18.2 <u>The manufacturer's and the authorities' implemented and planned safety measures</u>

1.18.2.1 As a result of the three cases involving loss of control in the winter of 2007/2008, a number of measures were implemented to increase safety margins. The purpose of the measures was primarily to ensure that take-off took place with a clean wing, and that the rotation rate of 3°/sec. was not exceeded. The following two warnings from the manufacturer illustrate the risk factors:

"Even small amounts of frost, ice, snow or slush on the wing leading edges and forward upper wing surface may adversely change the stall speeds, stall characteristics and the protection provided by the stall protection system, which may result in loss of control on take-off."

"Excessive rotation rates (exceeding 3 degrees per second) or over-rotations may lead to high pitch attitudes and angles of attack being attained while the aircraft is near the ground. This can reduce stall margins significantly resulting in stick shaker/pusher activation and potentially loss of control. Pilots must rotate smoothly towards the target pitch attitude then transition to speed control."

1.18.2.2 On 6 March 2008, Bombardier issued a temporary revision to the Aircraft Flight Manual (AFM), Temporary Revision RJ/155-2. The need to advice the flight crew about the following factors was stated to be the reason for the revision:

- Amended guidelines and correct use of Wing Anti-Ice System

- The importance of the clean wing concept for the aircraft type

- Changes in conditions which require tactile inspection of the wing's surface and leading edge

- Requirement relating to Wing Anti-Ice ON during taxiing in certain conditions

- Requirements relating to Wing Anti-Ice ON for all take-offs in icing conditions

- Change to the definition of ground icing conditions

- New procedures and limitations to reduce the tendency for high rotation rates and over-rotations

1.18.2.3 On 7 March 2008, the type certifying authority Transport Canada (TC) issued an Emergency Airworthiness Directive, no. CF-2008-15, titled *"Enhancement to Take-off Operational Safety Margins"* effective 10 March 2008. The directive required flight crew members to be informed within two weeks of the new limitations and additional procedures issued for the aircraft type after the mentioned instances of loss of control, and that the amendments had to be included in the aircraft flight manual. The directive stated that special emphasis should be placed on verifying that the pilots' checklists reflected the content of AFM as regards when Wing Anti-Ice must be switched on. The directive was revised on 20 August 2008 (AD CF-2008-15R1 follows as Appendix E). The amendment required all flight crew members to have special training in take-off procedures under winter conditions from 1 November 2008. This training requirement is discussed in more detail under 1.18.2.7.

1.18.2.4 The US Federal Aviation Administration, FAA, issued a corresponding airworthiness directive effective 21 April 2008 (Airworthiness Directive (AD) 2008-08-06). This replaced an existing AD from 2005 which referred to "Cold weather operations limitation".

1.18.2.5 On 19 March 2008, Bombardier issued a Flight Operations Note titled *―Take-off Safety Enhancements"*. The full document is enclosed (Appendix F). The note explains the background for the new limitations and additional procedures. In addition to detailing which temperatures and weather conditions that indicate that there is a risk of ice contamination on the wing, the document mentions a couple of implemented measures aiming to prevent an excessive rotation rate. The first is that warnings and descriptions of consequences of aggressive rotation have been included in the documentation. The other is that the flight director"s initial target for rotation has been reduced from 15° to 12°. This has been integrated in the most recent version of the Flight Control Computer, and the entire fleet is being upgraded continuously free of charge for the operators. While awaiting upgrades, the procedure is that the flight director pitch is set at 10° before take-off (using TOGA *(Take-off/Go-around)* button + pitch wheel).

1.18.2.6 During the 2008/2009 winter season, Bombardier held presentations at more than 30 different locations in North America, Europe, China, Kazakhstan and Mexico. The presentation focused especially on the wing's stalling characteristics, factors that can cause stalling during take-off in winter conditions and important aspects to avoid this. A number of animations from accidents and incidents involving loss of control upon take-off were also shown. Most of the material, including animations, has been made available on Bombardier's website. Bombardier concluded its presentations reminding those present that no take-off accidents have taken place in winter operations with the Wing Anti-Ice system ON.

1.18.2.7 The mandatory training requirement in AD CF-2008-15R1 from Transport Canada entails that the commander must have completed a course in winter operations in the last 12 months to take off when the air temperature is 5 °C or less. The same requirement applies to the first officer if piloting the aircraft during take-off. The requirement is considered to be met if the pilots have reviewed the online training program *"Bombardier Enhancement to Take-off Operational Safety Margins Training"*. If the pilots have not undergone such training over the last twelve months, they can still take off when the temperature is 5 °C or less, provided that they turn on Wing Anti-Ice just before take-off:

> *"If neither of the preceding requirements has been complied with [pilot annual training requirements not satisfied], the wing anti-ice system must be selected ON for take-off, just prior to thrust increase for take-off, if the OAT is 5 °C (41 °F) or below."*

1.18.2.8 Bombardier has also published an Initial Training Presentation and a slightly shorter Recurrent Training Presentation titled "Winter Operations Awareness take-off Safety Enhancement (TOSE)" on its website. The material is intended to create a basis for the operators" own winter training programs. (Links to various websites are given in the reference list in Ch. 6). In addition to courses for flight crew, course material for managers and ground crew is also available.

1.18.2.9 Report no. 5/2004 from the Air Accidents Investigation Branch (AAIB) in the UK, relating to the air accident involving CL-600-2B16 Series 604, N90AG at Birmingham International Airport on 4 January 2002, included the following safety recommendation (2003-60):

> *―It is recommended that the Federal Aviation Administration and Joint Airworthiness Authority[5] review the current procedural approach to the pre take-off detection and elimination of airframe ice contamination and consider requiring a system that would directly monitor aircraft aerodynamic surfaces for ice contamination and warn the crew of a potentially hazardous condition."*

1.18.2.10 The FAA rejected the recommendation in 2004 on the following basis:

> *―We do not concur. We have reviewed our current pre-takeoff contamination procedures and consulted with aviation de-icing experts within the FAA, commercial airlines, and other members of the internationally recognized Society of Automotive Engineers G-12 Aircraft Ground De-icing Committees concerning the feasibility and availability of an airframe ice contamination monitor and warning system. These experts have concluded that currently available systems vary in their level of sophistication and capabilities, and none are presently capable of or reliable enough to mandate their use."*

1.18.2.11 A corresponding recommendation to the one made by the AAIB was made by the Interstate Aviation Commission (IAC) in its reports relating to the accident in Moscow in 2007 and the accident in Armenia in 2008.

[5] *Processed by FAA and EASA*

1.18.2.12 EASA has assessed AAIB recommendation 2003-60 and concluded on 28 May 2010 that it would consider the regulations anew (EASA Safety Recommendation Reply). EASA acknowledges that the existing certification standard (CS-25), which assumes ice-free wing profiles when starting the take-off on the basis of operational procedures, may not be sufficient. Ice contamination that is hard to discover is mentioned as an example. To prevent aircraft from commencing take-off with contamination on the wings, EASA has initiated a task in the rulemaking inventory list (25.074). The work has not yet started and no schedule exists, but the following purpose has been established:

> *"…to propose new CS-25 provisions which will require applicants to perform an analysis of the on-ground wings contamination effect on takeoff performance degradation. …"*

Should analyses show that *a hazardous effect* as a result of contamination cannot be excluded; measures to reduce the risk must be implemented. A system monitoring the aircraft's aerodynamic surfaces is mentioned as one potential measure:

> *"The applicant would have to demonstrate that the effect on Takeoff performance degradation is not hazardous. If a hazardous effect is possible, then measures shall be put in place to alleviate the risk, which may include a system that monitors the aircraft aerodynamic surfaces."*

1.18.2.13 As mentioned in 1.6.2.7, the certification standards CS-25 related to protection against icing (25.1419 *Ice Protection*) have been made stricter at least once since the CRJ200 was certified.

1.18.2.14 Bombardier has previously stated that it has considered ice detection and warning systems while on ground, but considers that the technology is not sufficiently developed to be used on the CRJ200. For this type of aircraft it would be necessary to detect ice along the entire wing leading edge, and one challenge is that this occasionally is heated to more than 100 °C. The detectors would also be exposed to ice accretion during the flight. Instead, Bombardier has initiated a study to look into whether a technical solution which automatically or semi-automatically can activate a moderate wing leading edge heating mechanism while the aircraft is on the ground is practical (a concept similar to that developed for the Fokker 70 series).

1.18.3 The operator's implemented and planned safety measures

1.18.3.1 The operator Cimber Air briefed all of its pilots about this serious incident and emphasised the importance of correct take-off technique and de-icing. In addition, the operator has stated that it has complied with all requirements and recommendations issued by authorities and the manufacturer following this serious incident and the two take-off accidents with the aircraft type in the winter of 2007/2008. The safety department proposed making verification of Wing Anti-Ice ON mandatory by selecting EICAS anti ice page to be part of the checklist prior to take-off. A provision stating that both pilots must verify that the system settings are correct was included in the procedures.

1.18.3.2 The operator has expressed that the incident with OY-RJC was a wake-up call. The fact that data from the flight recorder identified several instances of stick shaker activation during take-off (see 1.11.2), was a contributing factor when Cimber, following the incident, considered introducing routine flight data monitoring (FDM) for both CRJ200 (MTOM approx. 24 000 kg) and ATR42/72 (MTOM approx. 18 500/21 500 kg)[6]. In late 2010/early 2011, Cimber Sterling stated that they had not introduced FDM for these aircraft types and that they had no plans for doing so as long as this is not an authority requirement.

1.18.3.3 To strengthen the transfer of experience and the lessons learned from the incident with OY-RJC, the crew has volunteered to participate in a video interview for use in the internal Crew Resource Management (CRM) training.

1.19 Useful or effective investigation techniques

In this investigation, a Sequential Time Events Plotting (STEP) diagram and a fault tree were used to map the chain of events and identify safety problems. Furthermore, risk assessment and barrier analysis with a basis in the U.S. Department of Energy (DOE) Worksheet were conducted. A selection of the methods and results are described in the analysis section and included as appendices to the report.

2. ANALYSIS

2.1 Introduction

2.1.1 The AIBN asserts that it is nowadays uncommon that an aircraft type used in regular transport of passengers is involved in so many accidents and incidents with clear common characteristics. The high occurrence rate is cause for concern. The most relevant issues in the CL-600 accidents and incidents have already been thoroughly investigated by accident investigation boards and the manufacturer, and measures have been implemented as new knowledge has been gained. The last three instances of stalling during take-off in icing conditions took place in the period 2007-2008. Following these, further measures have been implemented to increase the safety margins for the aircraft type in question during winter operations (see 1.18).

2.1.2 In its analysis, the AIBN assumes that the wing of OY-RJC was contaminated during the take-off, as calculations from Bombardier have shown. It has been established that the wing anti ice was off by mistake. The chain of events is considered to be typical of leading edge stall. In addition, symmetrical loss of lift on the inner wings after control was regained was registered (see 1.16.4).

2.1.3 It seems clear that the margins became too small with contamination on the wing in combination with the excessive rotation rate used during the take-off in question. The stall protection system which normally prevents stalling worked as intended. However, when it activated, the stall had already occurred at a significantly lower angle than expected. Fortunately, the crew succeeded in regaining control in this case, but when a stall occurs immediately after lift-off, the result will most likely be disastrous.

2.1.4 Bombardier has contributed with extensive analyses of this serious incident. Relevant factors have been described and discussed in previous accident reports. On this basis, the AIBN could limit the scope of its analysis to the following key questions:

[6] *FDM is mandatory only for passenger transport with aircraft exceeding 27 000kg MTOM*

- What did the contamination consist of, and how and why was the wing contaminated in this case?

- Are the implemented safety measures sufficient, or is there a need for additional measures?

Before attempting to answer these key questions, some comments to the certification of the aircraft type, as well as the chain of events and the factors pertaining to the take-off in question will be made.

2.2 Amended type certification requirements

2.2.1 The relevant certification standards for ice protection that applied when CRJ200 received its type certification (see 1.6.2.7 and 1.6.2.8), seem to not have factored in situations such as the one that arose when OY-RJC took off from Gardermoen on 31 January 2008. FAR/JAR 25.1419 primarily set requirements related to the system's ability and capacity to keep the aircraft sufficiently free of snow and ice - when activated. The requirements in FAR/JAR 25.1309 mainly focused on the system's reliability, as well as generating warning to the pilots in case of systems failure. The need for alerting the pilots should they forget to activate the system seems to have been overlooked.

2.2.2 The AIBN considers the later additions to CS/FAR 25.1419 relating to automatic activation or alerting the crew of this type of error to be confirmation that the safety deficiency has been realised, and that steps have been taken to close the identified „hole in the safety barrier‟. However, as procedural solutions are still permitted as an alternative, this gap has in reality not been closed after all (see 1.6.2.7). With the escalation of EASA‟s new „Rule Making Task‟, it is possible that requirements will be set for aircraft types certified in the future, entailing mandatory design solutions which prevent take-off with the anti-icing systems switched off during icing conditions if this is critical to safety (see 1.18.2.12). If so, this would be in line with the philosophy forming the basis for the introduction of the requirement for take-off configuration warning (see 1.6.2.9). The excellent developments in aviation safety have been characterised by the willingness of the aviation community to learn from each individual accident and to continuously introduce improvements where potential safety issues have been noted, instead of waiting until the number of accidents have become high enough to justify measures. The renowned Danish safety scientist Jens Rasmussen calls the first approach *–Evolutionary Safety Control”* and the latter *–Empirical Safety Control”.* The latter is most common in the roads sector and in workplace safety.

2.2.3 As the amended requirements do not have retroactive effect for aircraft which have already received a type certificate, they will probably not affect the CRJ200. However, the AIBN is of the opinion that the safety problem identified for this aircraft type cannot remain unresolved, and that it is necessary to consider implementing measures to bring the aircraft type more in line with applicable regulations and achieve the safety intended by the original type certification – although developments have shown that the regulations at the time were not complete in this respect. This issue is discussed further in 2.9.10.

2.3 The situation prior to take-off

2.3.1 <u>Flight preparations</u>

The flight preparations seem to have held the standard expected of such operations. The crew was in no doubt that de-icing was necessary, and they were aware that the conditions required Wing Anti-Ice to be activated at take-off. The available weather and runway conditions reports indicated moderate precipitation and no more than 3 mm of slush on the runway, which should permit normal operations.

2.3.2 De-icing/anti-icing

No factors have been uncovered relating to the de-icing and anti-icing which can be assumed to be of significance to the wing being contaminated upon take-off. The work was performed in line with applicable guidelines. Fluid temperature, grade, quantity and symmetry of the application have been documented and found to be in order (see 1.10.3.11). The possibility of the anti-icing fluids being degraded as a result of chemicals from the ground or heavy precipitation cannot be completely excluded, but is considered to be small.

2.3.3 Meteorological information

2.3.3.1 The most remarkable aspect of the weather that day was the large, wet snowflakes. Between the hours of 1650 and 1720, the observations changed from ”RASN” to ”SNRA”, i.e. a change where the mixed precipitation went from predominantly rain to predominantly snow. The temperature and dew point were stable at 0 °C in the relevant period, and there was no freezing precipitation which could create problems for air traffic. The wind direction from 150 degrees with a reported wind speed of 15 kt indicates that the aircraft's right wing, after de-icing, was more exposed to wind and drifting snow than the left, taking into consideration the taxiing route and the holding position for take-off.

2.3.3.2 The observed visibility values and valid weather reports indicated that the precipitation did not exceed moderate. Witness statements indicate that the water content of the snow was high, and the AIBN, like the Norwegian Meteorological Institute, believes that it cannot be excluded that the snowfall was heavy for some minutes when measured in water content (see 1.7.3). As mentioned in 1.10.3.10, no guidelines are issued for Hold-Over Time (HOT) in heavy snow.

2.3.3.3 Unlike in Norway, North America distinguishes between dark and daylight and takes into account temperature when evaluating precipitation intensity (see 1.7.5, tables 5 and 6). While Norwegian guidelines stipulate that heavy snow should not be reported until visibility has been reduced to 500 m, heavy snow would have been reported in the US and Canada at a visibility of 1600 m (1 Statute Mile) with the prevailing light and temperature conditions at Gardermoen when the incident took place.

2.3.3.4 Based on the above, the AIBN believes that there is reason to assume that the snowfall intensity at Norwegian airports in certain instances can be reported as moderate, while it is in fact heavy when measured in water content. Accordingly, flight crews may be led to believe that the wings are protected after anti-icing - in this case for at least one hour - while the HOT guidelines in reality do not apply. METAR does, strictly speaking, provide a poor basis for determining HOT, but is currently the only decision basis the flight crews have in addition to their own observations.

2.3.3.5 The AIBN knows that trials are currently taking place at several Canadian airports to test systems which detect precipitation intensity based on the water content of precipitation in order to estimate a more correct HOT. There will still be some uncertainty, partly as a result of the aircraft wings potentially being colder than the surroundings. AWOS (Automatic Weather Observing System) which is currently used at airports in Norway, probably also has the ability to measure precipitation intensity. While awaiting better systems, the AIBN believes that the Norwegian Meteorological Institute should reassess the Norwegian guidelines for precipitation intensity based on visibility values. A recommendation is made to this effect.

2.3.4 Runway status

2.3.4.1 It is in retrospect not possible to determine the exact depth of the contamination layer when OY-RJC took off at 1720 hours, but there is no doubt that the runway was contaminated with a mixture of slush and wet snow. The limit values for when take-off is permitted vary with the nature of the contamination (25 mm wet snow, 13 mm slush). The AIBN believes that there is no basis for claiming that the runway was more contaminated than permitted for take-off. The importance of the fact that the take-off took place from a contaminated runway is discussed further in 2.7.

2.3.4.2 The airliner which landed just before OY-RJC took off reported that the braking action was poorer than in the official measurements, experienced as „poor" rather than „medium". In spite of this, the runway remained open for about ten minutes after OY-RJC took off, and two more airliners landed before snow clearing started on the runway. Traffic management on a snowy day such as this, when snow clearing is continuous and one of the runways is closed, is challenging. The AIBN believes that the expectation that the main airport should be open and the flights should be on schedule create a pressure which can cause a reduction of the safety margins. Issues related to slippery runways in winter are discussed in a separate special study report currently being prepared by the AIBN.

2.3.5 Lining up for take-off

When OY-RJC positioned itself on the centre line on runway 19L, the runway conditions had changed compared with the latest published measurements. The runway was undoubtedly contaminated, and the information from the landing aircraft stating that the runway was slippery made the commander reassess whether taking off was advisable. His estimate for the crosswind component was correct, and the AIBN believes there is reason to assume that other pilots would have reached the same conclusion as the crew on OY-RJC. The conditions bordered the limits for the aircraft type CL-600-2B19. The crosswind component was possibly 1 kt too strong, but it was not apparent that taking off would be imprudent – assuming that the wings were not contaminated. Based on the information available to the crew, they were well within HOT. There was therefore no reason to believe that wing contamination was a problem – provided that Wing Anti-Ice was switched on.

2.3.6 Application of Wing Anti-Ice

The operator's procedures for application of Wing Anti-Ice were correct, and the crew was aware that they should activate the system just prior to application of take-off thrust. The first officer has explained that he was ready with his hand on the switch, but a distraction resulting from the commander's questions regarding reassessment of wind and runway conditions caused him to forget the switch. The omission was in other words a result of making a timely, professional evaluation. The result was that an essential barrier to prevent contamination of the wing leading edge and thereby prevent premature stalling failed. The importance of this is discussed in more detail in 2.7.

2.4 Take-off roll and rotation

Data from the DFDR shows that the first officer maintained good control of the aircraft while accelerating down the runway. The rotation did not start too early, but the movement was too fast. With a rotation rate of 6.1°/sec., the take-off in question stood out as the fastest among the 89 take-offs recorded on the two analysed flight recorders. There is, however, reason to note that the commander has stated that it was not the most extreme rotation he has experienced, and that the manufacturer has stated that a rotation rate of 6.1°/sec. is in the upper range of that observed in normal operations (see 1.18.1.1). Like other accident investigation boards in their investigations, the AIBN believes that the rotation rate would not have been a problem with clean wings. However, the margins were not present when the high rotation rate occurred in combination with other factors. This is discussed in more detail in 2.7.

2.5 Handling of the loss of control

The first officer's statement indicates that he cooperated with the stick pusher and avoided pulling back on the stick in spite of the ground being dangerously close. His reaction and rudder application most probably prevented this incident from becoming an accident. Animations from other accidents show that the nose was pulled up in several cases, with a resulting new asymmetric stall. Whether reduced lift at the wing root on OY-RJC had any influence in this regard (affects the pitching moment) has not been analysed. The fact that the commander quickly saw that Wing Anti-Ice was OFF and corrected this may have influenced positively on maintaining control of the aircraft in the following seconds.

2.6 Sources of wing contamination

2.6.1 Information about the fuel filled (temp. 3.5 °C) and the moderate quantity of fuel remaining from the previous flight indicates that the wings were not colder than the surroundings. The temperature at the airport remained at 0 °C, and the air moved well with winds of 15 kt. The de-icing and anti-icing fluids applied held a significantly higher temperature than the surroundings. The AIBN believes it unlikely that the temperature on the wing leading edge was at any time significantly less than 0 °C.

2.6.2 In general, the layer of protecting fluid (anti-icing fluid) becomes thinner on slanting surfaces than on horizontal surfaces after application. On the leading edge of a wing, the layer will be thinned as a result of run-off while the aircraft awaits take-off, and during take-off acceleration the thin layer on the leading edge disappears first. If the anti-icing fluid collapses for any other reason, for example as a result of strong winds, chemicals from the ground or heavy precipitation, snow can begin to form on the wings even before the take-off commences. However, the AIBN believes that this is unlikely in the incident with OY-RJC, an assumption supported by Bombardier's expert statements (see 1.10.3.11).

2.6.3 When the anti-icing fluid flowed off during acceleration, the wing on OY-RJC was left unprotected as the leading edge heat had not been switched on. At the same time, the wing leading edge was bombarded with precipitation at a steadily increasing rate. It is likely that the large, wet snowflakes, described by witnesses as sticky, remained on the wing and disturbed the airflow before they melted.

2.6.4 In addition, take-off from contaminated runways can create substantial wing contamination. The picture of the spray pattern in the water trough test in Figure 12 illustrates the problem. The AIBN has the impression that the manufacturer's aerodynamics expertise has not focused sufficiently on the potential effect of nose wheel spray before the issue was raised by this investigation. Nose wheel spray envelops the wing root during take-off from contaminated runways and hits the critical area – the leading edge „break" – where the manufacturer points out that the stall initiates (see 1.16.7 and 1.16.8).

2.6.5 The AIBN believes it likely that critical areas of the wing of OY-RJC were exposed to a substantial quantity of contamination as a result of spray from the nose wheel during take-off. The spray pattern during the take-off with OY-RJC is assumed to have corresponded to the pattern in figure 12. The layer of slush and wet snow on the runway was not particularly thick (see 1.10.2.5). If the contamination remains after the nose wheel lifts from the ground, this may induce disturbances in the airflow and result in a leading edge stall before the protection systems can kick in. The manufacturer has stated that the WAI system can prevent any contamination from attaching itself to the wing leading edge (see 1.6.2.6). As known, the WAI was OFF during OY-RJC's take-off.

2.6.6 If the aircraft loses lift near the wingtips, the nose section will pitch up. If lift is lost near the wing root, the forces will have a tendency to keep the nose section down, as was the case here. Calculations made by the manufacturer indicate a symmetric lift loss was near/towards the wing root when control had been regained (see 1.16.5). The AIBN believes that the loss of lift most likely came from contamination from nose wheel spray as a result of the layer of slush on the runway.

2.6.7 Warnings in the flight manual relating to hazards in connection with taxiing on contaminated surfaces show that spray from the nose wheel had been considered in other contexts than take-off. This problem had, however, been emphasised a lot less than other sources of wing contamination, such as rime frost. The AIBN believes the need for and the possibility of diverting nose wheel spray away from critical wing areas should be looked into. An assessment should also be made whether to discuss this hazard in the aircraft's documentation, and a recommendation is made in this connection. The issue may be claimed to apply to other low-winged aircraft as well. However, the AIBN has chosen to limit its recommendation to apply to the aircraft type in question, which has proven to be especially vulnerable to contamination of the wing leading edge.

2.7 Factors contributing to the wing stalling

2.7.1 <u>Introduction</u>

2.7.1.1 A simplified fault tree analysis was used as a tool to structure the analysis and illustrate the factors contributing to the wing stalling. The fault tree and the legend for the symbols used in the diagram can be found in Appendix H.

2.7.1.2 The above analysis assumes certain parameters as given. For example, the airfoil section is a given, and it is assumed that the aircraft has no reliable ice detection system while on the ground. The ground effect is always present, and crosswind within the applicable limits must be expected. The result of the analysis shows that two variables stand out as pertaining to this case, i.e. the wing contamination and the excessive rotation rate.

2.7.1.3 The fault tree in Appendix H also illustrates what may have caused the contamination of the wing, as well as known and potential underlying factors in the excessive rotation. The most important factors are discussed in the next paragraph.

2.7.2 Assessment of factors

2.7.2.1 The effect of a contaminated wing leading edge has been thoroughly explained earlier, for example in AAIB report 5/2004. In short, contamination contributes to premature *leading edge airflow separation,* see Figure 4. According to the manufacturer, wing contamination in the case of OY-RJC contributed to reduce the stall angle by about 3 degrees.

2.7.2.2 The effect of excessive rotation rate contributes to reduce the safety margins in the critical phase where the stall margin is already reduced as a result of the ground effect. When taking off in crosswind, the margins are reduced further for the wing on the lee side of the fuselage. The effect of the crosswind on aircraft with swept wings corresponds to sideslip. The AIBN has assessed the basis for the manufacturer's calculations which showed that crosswind and ground effect combined to reduce the stall angle by about 2 degrees. The crosswind component used by Bombardier in its calculations was 15 kt, whereas the real value was about 11 kt. The AIBN therefore believes that the crosswind contribution was slightly less than 1 degree, and that the combined effect of these two factors is less than 2 degrees. The high rotation this close to the ground was adverse, but the stall margins would have been sufficient had the wings been „clean".

2.7.2.3 Other factors which may have contributed to premature stalling have also been assessed (see 1.16.10). The AIBN has not considered it practical to examine any of these factors in greater depth in this investigation.

2.7.2.4 The requirement that aircrew members must have completed special training in winter operations during the last year in order to take off with the aircraft type in temperatures of 5 °C or less may seem strict. In practice, however, this requirement can easily be circumvented by choosing "Wing Anti-Ice ON" (see 1.18.2.7). The AIBN believes this shows that the manufacturer considers Wing Anti-Ice ON to be critical to prevent contamination of the wing leading edge under certain winter operations, and that ensuring that the system is activated is the most important individual factor to prevent an accident during take-off. In a safety perspective, training requirements and information campaigns are considered to have relatively little effect, as they more often address the symptoms rather than the causes of the problem.

2.7.2.5 The Accident Investigation Board considers the measure described by Cimber, to verify Wing Anti-Ice ON prior to take-off and require both pilots to check this, to be an improvement. Nonetheless, it is yet another example of a soft barrier. Take-off in winter conditions without "WAI ON" has proven to be so critical to safety that the AIBN believes it warrants a more fundamental approach. This will be discussed further in the next paragraph.

2.8 Assessment of the need for additional safety measures

2.8.1 The high number of accidents compared with the modest number of reported incidents is a sign of high risk. When stalling occurs just after lift-off, the outcome will most likely be catastrophic. AIBN believes that the degree of under-reporting must be assumed to be relatively low for such incidents. Loss of control at low altitude with passengers on board will be more difficult to conceal than many other serious aircraft incident types, and flight crews will want to seek knowledge of what caused the loss of control.

2.8.2 Appendix I shows the barrier analysis the AIBN prepared to assess the defence mechanisms against premature stalling in winter conditions. The defence mechanisms related to the two identified variables which stood out in the fault tree analysis – wing contamination and excessive rotation rate – were assessed separately. Both existing and missing barriers were mapped, and their function and contribution to the incident were analysed.

2.8.3 Measures implemented and planned following this incident have been described in 1.18 and appear in the table in Appendix I. The defence mechanisms which are to prevent, or contribute to preventing, a take-off with wing contamination include weather service, runway preparation, de-icing, heated wing leading edges, spray deflection and a system to detect wing contamination while the aircraft is on the ground. Barriers which are to prevent excessively high rotation rates close to the ground include procedures which describe maximum rotation rate, training, manual monitoring of the rotation rate (by the PNF), position of the flight director pitch bar upon take-off and procedures to check and verify the aircraft's mass, balance and trim settings. (See Appendix I – Note that the list of barriers is not necessarily complete).

2.8.4 It is evident that it has been attempted to increase the safety margins primarily through soft barriers such as procedures, education and training. The measure involving lowering the flight director pitch command bar (see 1.18.2.5) can be asserted to be a stronger barrier, as it entails making a physical change to pitch guidance on a primary cockpit instrument. The measure probably have a beneficial effect as regards preventing an excessive rotation rate, however, it does not automatically give correct rotation or direct guidance which the pilot can follow until initial climb-out speed (V_2 + 10 kt) is achieved.

2.8.5 Cimber Sterling has stated that they will not introduce Flight Data Monitoring (FDM) for CRJ200 as long as this is not required by the authorities (see 1.18.3.2). The AIBN believes that an operator with a well-functioning safety management system (SMS) will be aware of the wing of the aircraft type being particularly vulnerable to contamination, and that excess rotation at take-off is a threat. FDM could be a suitable tool for uncovering the prevalence of faulty take-off techniques and monitor the effect of implemented measures. Without this tool, the operator would have to find other ways of monitoring and correcting take-off techniques, e.g. simulator training and supervision.

2.8.6 As shown in Appendix I, the AIBN has assessed where additional safety actions are considered necessary and has listed them according to priority. The AIBN has also assessed whether automatic detection measures in the event of ice on the wing would have prevented the incident in Oslo (Recommendation UK AAIB 2003-60, see 1.18.2.12). If the wing on OY-RJC was free of ice until the anti-icing fluid had flowed off during the take-off roll, the warning would probably have come too late. The AIBN considers it favourable that EASA has taken action based on the safety issue identified by the AAIB (see 1.18.2.12). In this report, the AIBN issues a safety recommendation focusing on the same safety issue without prescribing the fix (see 2.9).

2.8.7 In its presentations, the manufacturer emphasises that no aircraft have stalled during take-off with Wing Anti-Ice ON, and gives the impression that the wing leading edge heater would have prevented both this serious incident and loss of control occurrences during take-off (see 1.18.2.6). This aspect is discussed in detail in the next paragraph.

2.9 Areas where safety measures seem to be required

2.9.1 After taking into account implemented and planned measures, the AIBN believes to have a basis for making recommendations in the following areas:

- Heating of wing leading edge
- Wing contamination as a result of nose wheel spray
- Norwegian guidelines for evaluation of precipitation intensity

2.9.2 The reasoning for making recommendations for the two areas nose wheel spray and precipitation intensity is stated in 2.6 and 2.3, respectively.

2.9.3 The relevant wing profile, without slats or equivalent, has proven to be particularly sensitive as regards contamination. The system for leading edge heating is considered a crucial safety barrier to prevent contamination, and thus prevent premature stalling and a catastrophic accident during take-off in certain winter conditions. The manufacturer Bombardier maintains that WAI ON solves this fundamental problem of loss of control during take-off, and the AIBN believes that the importance of the Wing Anti-Ice system must be reflected accordingly in the defence mechanisms that aim to prevent errors and omissions. As of today, there are no warning systems that discover if the crew has forgotten to select Wing Anti-Ice ON before applying take-off thrust.

2.9.4 The recognised priority regime of the manufacturers" safety measures is that barriers built into the design which reduce or eliminate dangers are most important (Risk reduction by design). Then, if it is not possible to prevent exposure through design-related measures, the hazard must be safeguarded. Technical/physical protective barriers are preferred over soft barriers such as training, information and warnings (Information for user). The need for additional precautions must also be evaluated (Source: CEN, 1991. EN 292).

2.9.5 Experience with this aircraft type has shown that soft procedure-based safety barriers are too weak to solve the problem of loss of control during take-off in winter conditions. In spite of the fact that procedural improvements have been successively introduced as a result of seven catastrophic accidents in connection with take-off or go-around since 1997, the fundamental safety problem has not yet been solved. The vulnerability was demonstrated again in this serious incident in Oslo.

2.9.6 The importance of WAI ON indicates that there is a need for a reliable system to prevent aircraft from taking off without heating the leading wing edge when necessary. A barrier based on the use of checklists and memory for activation is not sufficient when the consequences of forgetting the barrier may be fatal. The fact that it is necessary to postpone activating the switch after de-icing until just before commencing take-off, increases the likelihood of forgetting.

2.9.7 One option for compensating for what the AIBN deems to be an unacceptable risk is to impose greater limitations for winter operations with the aircraft types in question. For such operative limitations to have sufficient safety effect, they should in reality entail that flying is only permitted if the conditions make taking off safe without the WAI system being activated. Alternatively, design changes could be considered. Provided that Bombardier is right when claiming that leading edge heating solves the fundamental problem, the design of a reliable system to ensure Wing Anti-Ice ON may be a possible solution to avoid extraordinary restrictions which would limit the use of the aircraft type. Take-off performance was not an issue in the incident involving OY-RJC, but activation of the WAI system results in a performance penalty which is a possible incentive to avoid unnecessary use of the system. This factor must also be taken into account when searching for satisfactory solutions.

2.9.8 The Accident Investigation Board believes that the accidents and incidents (Table 7) have caused uncertainty as regards safety during take-off and go-around in winter conditions with the relevant CL-600 models. The AIBN believes that the safety measures that have gradually been introduced following the individual incidents of loss of control (see 1.18.2) have neither individually nor as a whole resulted in a definitive solution to the problem. There is therefore, in the opinion of the AIBN, a need for a more fundamental approach to this safety-critical issue. When the original analyses of systems safety that formed the basis for the type certification were carried out (see 1.6.2.8), the current experiences from winter operations had not yet been had. The AIBN believes that similar analyses could not have been carried out today without the accidents and incidents being lent significant weight, as the purpose of these provisions in the certification standards was precisely to convince the type-certifying authority that all safety aspects had been sufficiently covered.

2.9.9 The design of a system which can detect parameters indicating a need for leading edge heating and warn the crew should they forget to activate the system could be one option. Another possibility may be designing the system so that Wing Anti-Ice is automatically switched on upon take-off. The first alternative correlates to the philosophy behind take-off configuration warning, where the crew is alerted of the situation so that they can interrupt the take-off if necessary. The other alternative, with automatic tapping of bleed air from the engines, can for example be activated if the temperature is below a critical value, the flaps are down and N1 exceeds a certain value. If „WAI ON" has not been taken into consideration in the take-off calculations, automatic activation may, however, create new problems as regards the aircraft's take-off performance.

2.9.10 The AIBN will not explore further the opportunities and limitations as regards systems design. Whether the planned system with leading edge heating at lower temperatures while the aircraft is on the ground changes the situation (see 1.18.2.14), has not been clarified. It is left to the type certificate holder (Bombardier) to develop solutions which take into account the identified safety issue. Both alternatives introduced above and Bombardier's plans for an ice prevention system while the aircraft is on the ground will probably entail extensive engineering, approvals and substantial costs. The AIBN does not rule out that there may as well be other design changes that may solve the problem.

3. CONCLUSIONS

In this investigation, the AIBN believes to have confirmed that known factors such as wing contamination in combination with an excessive rotation rate contributed to a CL-600 series aircraft stalling during take-off in winter conditions. Even though procedural improvements have successively been implemented as seven aircraft have lost control and had catastrophic accidents since 1997, the essential safety problem has not been solved. A factor which has not been discussed to any extent in connection with previous accidents is the effect of the wing being contaminated by spray from the nose wheel when taking off from a contaminated runway. That the wing leading edges are heated (Wing Anti-Ice ON) seems to be critical. Accordingly, there is a need for reliable systems which ensure this.

3.1 Findings

a) The aircraft was registered in accordance with the regulations and held a valid certificate of airworthiness.

b) The mass and centre of gravity of the aircraft were within the prescribed limits at the time of the incident.

c) There was no evidence of any technical defect or malfunction in the aircraft that could have contributed to the accident.

d) The crew members held valid licences and qualifications for the aircraft type.

e) There was no evidence of any shortcomings in the de-icing / anti-icing which can be assumed to be of importance to the wing being contaminated upon take-off.

f) The wings were not cold-soaked after the previous flight.

g) The take-off took place before the hold-over time expired in line with the applicable guidelines for moderate snow.

h) It cannot be ruled out that the precipitation intensity measured in water content was heavy for a few minutes after de-icing, while the aircraft was waiting to take off. It is, however, unlikely that the anti-icing fluid collapsed and that snow started building up on the wings before the take-off commenced.

i) Norwegian guidelines for assessing precipitation intensity are based on visibility values which are less restrictive than more recently published North American guidelines.

j) The weather conditions indicated that Wing Anti-Ice ON was required, and the crew was aware of this.

k) The aircraft's system to prevent ice on the wing leading edges should according to the checklist be switched on just prior to take-off, but this was forgotten due to a distraction related to an operational issue. There are no systems for discovering such omissions.

l) The runway was covered with a layer of slush and wet snow, probably at almost maximum permitted depth.

m) Spray from the nose wheel envelops the wing root and a critical area of the wing leading edge upon take-off from contaminated runways. This fact is not emphasised to any extent in the aircraft's documentation and training material.

n) The rotation took place at the correct speed, but with a higher rotation rate than recommended (6.1°/sec. compared to 2.5-3.0°/sec.).

o) The stall protection systems functioned as intended. However, stalling took place at about 5 degrees below the expected stall angle, just before the stick shaker and stick pusher were activated.

p) Calculations based on the flight recorder data show that the wing leading edge was contaminated when the aircraft lifted off.

q) Calculations based on flight recorder data and simulations show that the wing produced less lift than expected at the wing root also after regaining control.

r) A catastrophic accident was prevented by the stick pusher and the crew's handling of the loss of control in combination.

s) There have been seven major accidents and at least two serious incidents with loss of control probably related to wing contamination on CL-600 series aircraft in the period 1997-2008.

4. SAFETY RECOMMENDATIONS

The investigation of this serious incident has identified several areas where the Accident Investigation Board Norway sees a need for making safety recommendations to improve flight safety[7]

Safety recommendation SL no. 2011/03T

Experience has shown that contaminated wing leading edges on aircraft of the CL-600 series during take-off can cause a premature stall with an uncontrollable wing drop and a risk of a catastrophic outcome. Activation of the Wing Anti-Ice system is considered a crucial barrier to prevent a contaminated wing leading edge. In order to increase the safety margins, the AIBN recommends that Transport Canada and EASA require the type certificate holder (Bombardier) to introduce non-procedural safety barriers (for instance take-off warning or automatic activation) to ensure that the wing anti-ice system on affected CL-600 series aircraft is activated on take-off in certain winter conditions.

Safety recommendation SL no. 2011/04T

Until satisfactory technical/physical safety barriers have been introduced to ensure that the wing anti-icing system on CL-600 series aircraft is activated on take-off

[7] The Ministry of Transport and Communications ensures that safety recommendations are presented before the aviation authorities and/or other relevant ministries for assessment and follow-up, cf. Section 17 of the Regulations relating to public investigation of accidents and incidents in civil aviation.

when this is critical to safety (see Safety recommendation 2011/03T above), the AIBN recommends that Transport Canada and EASA impose more severe restrictions on winter operations on the affected aircraft. The restrictions should in effect entail that flying is only permitted if the conditions make it safe to take off without Wing Anti-Ice being activated.

Safety recommendation SL no. 2011/05T

Upon take-off from contaminated runways, the wing root on aircraft of the CL-600 series will be enveloped by spray from the nose wheel. The wing leading edges become contaminated in the area where the airflow first separates when stalling. If the contamination does not vaporise, this area may become rough, which will reduce the stalling angle of the aircraft. The AIBN believes that this aspect has not been sufficiently emphasised and recommends the manufacturer Bombardier to consider the need for solutions which can contribute to diverting the spray away from the wing. An assessment should also be made whether this hazard should be discussed in the aircraft's documentation.

Safety recommendation SL no. 2011/06T

The investigation has revealed that the Norwegian guidelines for assessing precipitation intensity based on visibility values are less restrictive than more recently published North American guidelines. The guidelines are of importance to how long flight crews can expect de-icing fluid to prevent contamination of the aircraft's aerodynamic surfaces after de-icing (Hold-Over Time). The AIBN recommends that the Norwegian Meteorological Institute study the research results that form the basis for the new guidelines in the USA and Canada, and any other relevant documentation, and consider whether the Norwegian guidelines should be amended to prevent aircraft from taking off with contamination on the wings.

The Accident Investigation Board of Norway

Lillestrøm, 11 April 2011

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8. IAC Air Accident Investigation Commission Final Report on Accident with CL-600-2B19, reg. EW-101PJ, at Zvartnots Airport, Republic of Armenia February 14, 2008 – Uncommanded roll immediately after takeoff, frost contamination of wings

APPENDICES

Appendix A: Abbreviations

Appendix B: Aerodrome Ground Movement Map Oslo Airport Gardermoen (ENGM)

Appendix C: Guidelines for Holdover times Clariant Safewing MP II FLIGHT Type II Fluid Mixtures as a Function of Weather Conditions and OAT

Appendix D: Selection of Flight Data Recorder Parameters

Appendix E: Transport Canada Airworthiness Directive AD CF-2008-15R1 – Enhancement to Takeoff Operational Safety Margins including Excerpt of AFM Temporary Revision RJ/155-6

Appendix F: Bombardier Flight Operations Note – Takeoff Safety Enhancements

Appendix G: The Estimation of Snowfall Rate Using Visibility - Abstract

Appendix H: Fault Tree Analysis

Appendix I: Barrier Analysis

Appendix J: Transport Canada‟s comments to the draft final investigation report

ABBREVIATIONS

AFM	Aircraft Flight Manual
AIC	Aeronautical Information Circular
AIP	Aeronautical Information Publication
AMM	Aircraft Maintenance Manual
AOA	Angle of Attack
AOC	Air Operator Certificate
ASDA	Accelerate Stop Distance Available
ATIS	Automatic Terminal Information Service
CS	Certification Standard
CVR	Cockpit Voice Recorder
DFDR	Digital Flight Data Recorder
EASA	European Aviation Safety Agency
EICAS	Engine Instrumentation and Crew Alerting System
FCOM	Flight Crew Operations Manual
FDR	Flight Data Recorder
FRP	Final Release Person (de-icing)
FAA	Federal Aviation Authority
HOT	Hold-Over Time
hPa	Hectopascal
IAC	Interstate Aviation Commission
IAS	Indicated Air Speed
JAR	Joint Aviation Requirements
JAA	Joint Aviation Authorities
KIAS	Kt Indicated Air Speed
kt	Knot(s), nautisk mil per time
MAC	Mean Aerodynamic Chord
MCTOM	Maximum Certificated Take-Off Mass
METAR	Rutinemessig værobservasjon for luftfarten (i meteorologisk kode)
MTO	Menneske-Teknologi-Organisasjon
MTOM	Maximim Take-Off Mass
NTSB	National Transportation Safety Board
OM	Operations Manual

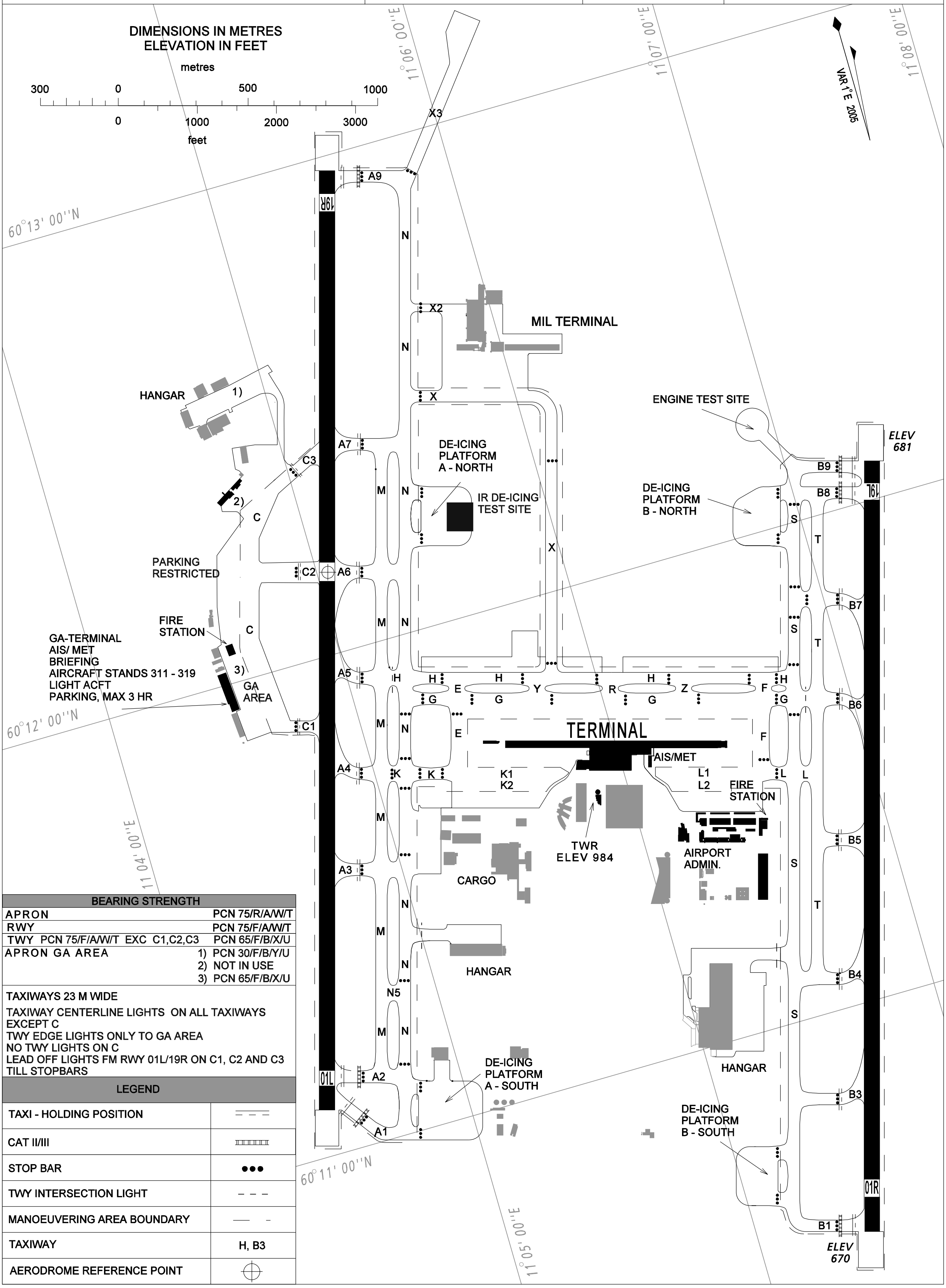
OPC	Operator Proficiency Check
p.o.b.	Personer om bord
PC	Proficiency Check
PF	Pilot Flying
PNF	Pilot Not Flying (også kalt Pilot Monitoring, PM)
QNH	Høydemåler innstilt slik at høyden over havet vises når man står på bakken
RWY	Runway
SOP	Standard Operating Procedures
SPS	Stall Protection System
TAF	Værvarsel for flyplass (MET kode)
TODC	Take Off Data Computer
TOGA	Take-off / Go-around
TORA	Take-Off Run Available
TSB	Transportation Safety Board
UTC	Co-ordinated Universal Time
V_s	Stalling speed, steilehastighet
WAI	Wing Anti-Ice
WOW	Weight Off Wheels

AERODROME GROUND MOVEMENT CHART

APRON ELEV 673 FT

TWR (W)	118.300 MHz
TWR (E)	120.100 MHz
GND (N)	121.925 MHz
CLR	121.600 MHz

OSLO GARDERMOEN
NORWAY



BEARING STRENGTH	
APRON	PCN 75/R/A/W/T
RWY	PCN 75/F/A/W/T
TWY PCN 75/F/A/W/T EXC C1,C2,C3	PCN 65/F/B/X/U
APRON GA AREA	1) PCN 30/F/B/Y/U
	2) NOT IN USE
	3) PCN 65/F/B/X/U

TAXIWAYS 23 M WIDE

TAXIWAY CENTERLINE LIGHTS ON ALL TAXIWAYS EXCEPT C
TWY EDGE LIGHTS ONLY TO GA AREA
NO TWY LIGHTS ON C
LEAD OFF LIGHTS FM RWY 01L/19R ON C1, C2 AND C3 TILL STOPBARS

LEGEND	
TAXI - HOLDING POSITION	— — —
CAT II/III	
STOP BAR	●●●
TWY INTERSECTION LIGHT	– – –
MANOEUVERING AREA BOUNDARY	—— –
TAXIWAY	H, B3
AERODROME REFERENCE POINT	⌖

CHANGES: CORRECTED TAXIWAY GEOMETRY, ADDED DE-ICING HANGAR + CHANGED TEXT

TABLE 7 - Guidelines for Holdover times Clariant Safewing MP II FLIGHT Type II Fluid Mixtures as a Function of Weather Conditions and OAT

CAUTION: THIS TABLE IS FOR DEPARTURE PLANNING ONLY AND SHOULD BE USED IN CONJUNCTION WITH PRE-TAKEOFF CHECK PROCEDURES.

Outside Air Temperature		Manufacturer Specific Type II Fluid Concentration Neat-Fluid/Water (Volume %/Volume %)	Approximate Holdover Times Under Various Weather Conditions (hours: minutes)						
Degrees Celsius	Degrees Fahrenheit		Active Frost	Freezing Fog	Snow/Snow Grains	Freezing Drizzle*	Light Freezing Rain	Rain on Cold Soaked Wing**	Other‡
-3 and above	27 and above	100/0	8:00	3:30-4:00	1:00-1:35	1:20-2:00	0:45-1:25	0:10-1:30	
		75/25	5:00	2:30-4:00	0:40-1:20	1:15-2:00	0:30-0:55	0:05-1:20	
		50/50	3:00	0:55-1:45	0:10-0:25	0:20-0:30	0:10-:015	CAUTION: No holdover time guidelines exist	
below -3 to -14	below 27 to 7	100/0	8:00	0:55-1:45	0:40-1:05	***0:35-1:30	***0:25-0:45		
		75/25	5:00	0:40-1:10	0:20-0:40	***0:25-1:10	***0:30-0:40		
below -14 to -25	below 7 to -13	100/0	8:00	0:30-0:50	0:15-0:30				
below -25	below -13	100/0	**CLARIANT SAFEWING MP II FLIGHT Type** II fluid may be used below -25 °C (-13 °F) provided the freezing point of the fluid is at least 7 °C (13 °F) below the OAT and the aerodynamic acceptance criteria are met. Consider use of **SAE Type I** when **CLARIANT SAFEWING MP II FLIGHT Type** II fluid cannot be used.						

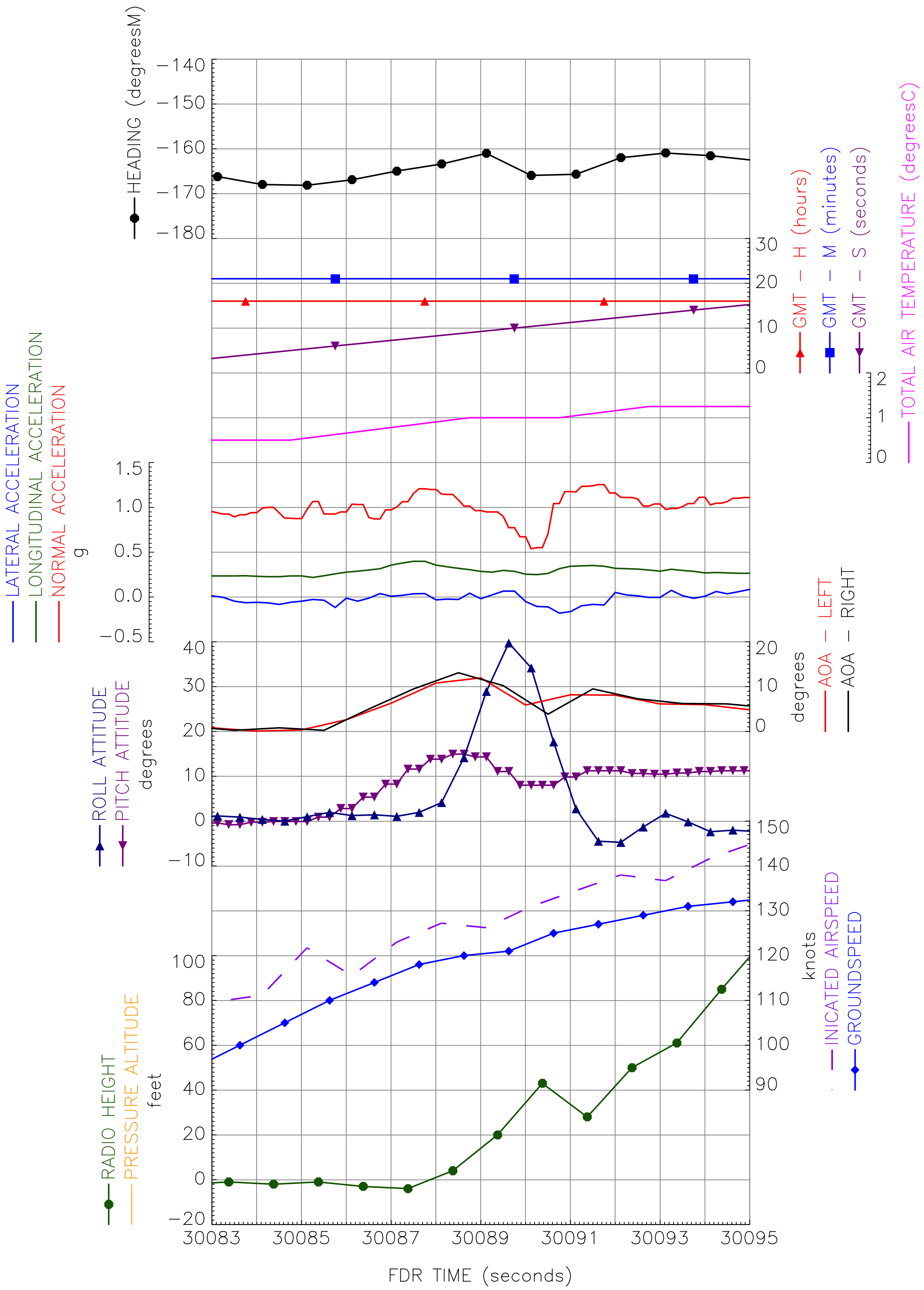
THE RESPONSIBILITY FOR THE APPLICATION OF THESE DATA REMAINS WITH THE USER.

* Use light freezing rain holdover times if positive identification of freezing drizzle is not possible
** This column is for use at temperatures above 0 °C (32 °F) only
*** No holdover time guidelines exist for this condition below -10 °C (14 °F)
‡ Snow pellets, ice pellets, heavy snow, moderate and heavy freezing rain, and hail

CAUTIONS:

- THE TIME OF PROTECTION WILL BE SHORTENED IN HEAVY WEATHER CONDITIONS. HEAVY PRECIPITATION RATES OR HIGH MOISTURE CONTENT, HIGH WIND VELOCITY, OR JET BLAST MAY REDUCE HOLDOVER TIME BELOW THE LOWEST TIME STATED IN THE RANGE. HOLDOVER TIME MAY BE REDUCED WHEN AIRCRAFT SKIN TEMPERATURE IS LOWER THAN OAT.
- CLARIANT SAFEWING MP II FLIGHT TYPE II FLUID USED DURING GROUND DEICING/ANTI-ICING IS NOT INTENDED FOR AND DOES NOT PROVIDE PROTECTION DURING FLIGHT.

Selection of Flight Data Recorder Parameters



Take-off OY-RJC – Selected parameters plotted by AAIB UK

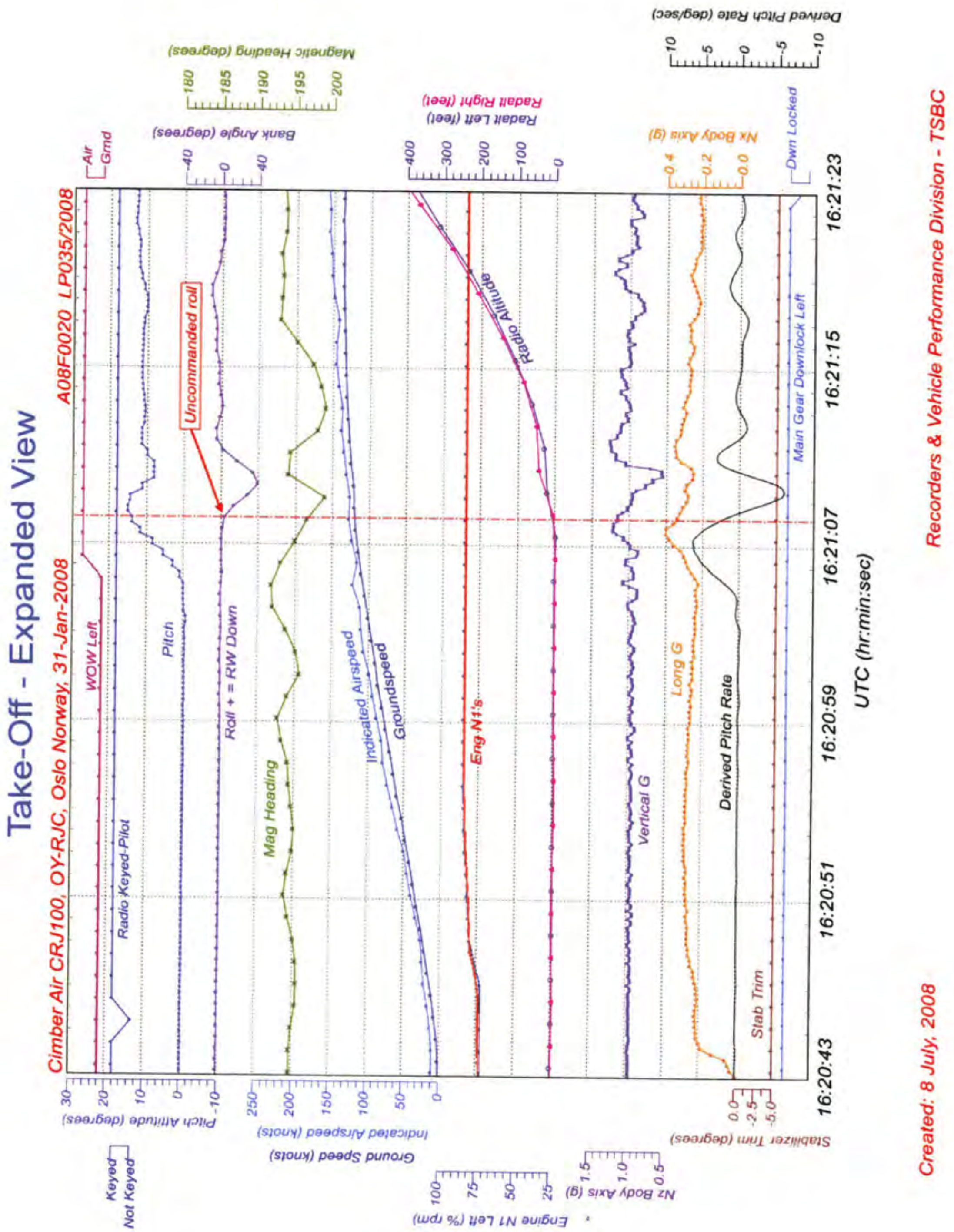


Figure 3: DFDR plot showing expanded view of take-off.

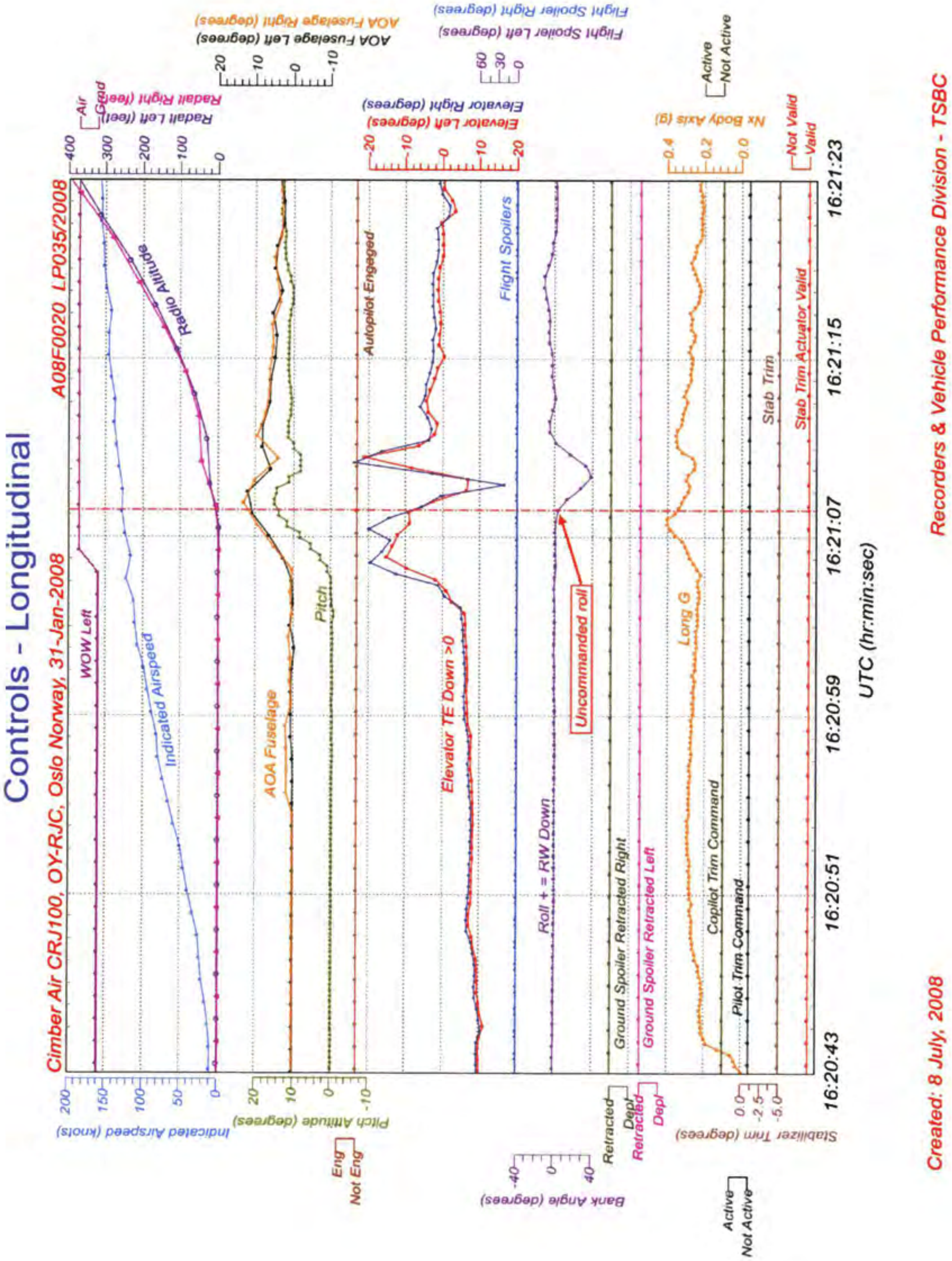


Figure 4: DFDR plot of longitudinal controls.

Transport Canada — Transports Canada

TP 7245E

No. **CF-2008-15R1** — 1/2
Issue Date **20 August 2008**

AIRWORTHINESS DIRECTIVE

The following airworthiness directive (AD) may be applicable to an aircraft which our records indicate is registered in your name. ADs are issued pursuant to ***Canadian Aviation Regulation*** **(CAR) 593**. Pursuant to **CAR 605.84** and the further details of **CAR Standard 625, Appendix H**, the continuing airworthiness of a Canadian registered aircraft is contingent upon compliance with all applicable ADs. Failure to comply with the requirements of an AD may invalidate the flight authorization of the aircraft. Alternative means of compliance shall be applied for in accordance with **CAR 605.84** and the above-referenced **Standard**.

This AD has been issued by the Continuing Airworthiness Division (AARDG), Aircraft Certification Branch, Transport Canada, Ottawa, telephone 613 952-4357.

Number: **CF-2008-15R1**

Subject: **Enhancement to Takeoff Operational Safety Margins**

Effective: 3 September 2008

Revision: Supersedes Airworthiness Directive CF-2008-15 issued on 7 March 2008

Applicability: All Bombardier Inc. Model CL-600-2B19 aircraft.

Compliance: When indicated, unless already accomplished.

Background

Following three recent accidents/incidents where Bombardier CL-600-2B19/CL-600-2B16 aircraft experienced un-commanded roll during take–off, Transport Canada Civil Aviation (TCCA) has determined that it is necessary to further enhance the airplane flight manual (AFM) limitations and procedures to ensure safe operation, particularly in cold weather or icing conditions.

The original issue of this directive mandated the introduction of additional limitations and procedures to the AFM and required that any operator's Pilot's Checklist fully reflects these procedures. In order not to compromise the takeoff operational safety margin, strict adherence to all the AFM procedures and limitations was required.

Revision 1 of this directive mandates the amendment of the AFM by inserting Temporary revision (TR) RJ/155-5 which, in addition to retaining the limitations and procedures introduced to the AFM Limitations Section through AFM TR RJ/155-2, now also requires specific pilot training on or before 1 November 2008 with regard to enhanced take-off procedures and winter operations.

Corrective Action

Part I – AFM Changes.

Within 14 days after the effective date of this directive, accomplish the following:

1. Amend the AFM by inserting TR RJ/155-5, dated 7 August 2008 or later approved revision.
2. Insert a copy of this directive in the AFM.
3. Advise all flight crews on the changes introduced through the AFM TR.

Part II – Operator's Pilot's Checklist.

Within 14 days after 10 March 2008 (the effective date of the original issue of this directive), review the "Pilot's Checklist" to ensure that the instructions regarding selection of the wing anti-ice system to **"ON"**, as specified in the AFM Limitations Section, are incorporated.

Authorization: For Minister of Transport, Infrastructure and Communities

Derek Ferguson
Acting Chief, Continuing Airworthiness

Contact: Mr. Richard Topham, Continuing Airworthiness, Ottawa, telephone 613.952.4428, facsimile 613.996.9178 or e-mail tophamr@tc.gc.ca or any Transport Canada Centre.

LETTER OF TRANSMITTAL

REASON FOR ISSUE

Temporary revision to advise the flight crew of the following:

- Wing Anti-Ice System Limitation,
- Wing Anti-Ice Piccolo Duct Damage Suspected abnormal procedure,
- Emphasize and re-state the importance of the 'clean wing' concept for the CL600-2B19 airplane,
- Advise of a change to the conditions for a tactile inspection,
- Advise that the use of wing anti-ice is now required during certain taxi operations,
- Advise that wing anti-ice is now required for all take-off operations when in icing conditions,
- Advise of a change to the definition of ground icing conditions,
- Advise of new procedures and limitations to reduce the tendency for high rotation rates and over-rotations,
- Advise that if the wing anti-ice system has been selected ON for take-off, the cowl anti-ice system must also be selected ON,
- Mandate Enhanced Take-Off Procedures and Winter Operations Training,
- Revise single engine taxi data,
- Incorporate SB A601R-30-032 effectivity, and
- Supersede TR RJ/155-5.

INSTRUCTIONS FOR INSERTION OF THIS TEMPORARY REVISION

(1) Insert the Record of Temporary Revisions in the front portion of the Airplane Flight Manual.

(2) Remove and destroy the pages and the Letter of Transmittal of Temporary Revision No. TR RJ/155–5.

(3) Insert the pages of this Temporary Revision in the Airplane Flight Manual as instructed at the top of each page.

(4) Record the insertion of this Temporary Revision on the Record of Temporary Revisions page.

(5) Retain this page for record purposes.

LIST OF PAGES AFFECTED BY THIS TEMPORARY REVISION

- Volume 1:
  - 02–00–1 <MST>,
  - 02–04–2,
  - 02–04–3,
  - 02–04–4,
  - 02–04–5 <MST>,
  - 02–04–6 <MST>,
  - 05–14–2, and
- Volume 4:
  - 07–15–31 <0090>.

INSERT IN LIMITATIONS - OPERATING LIMITATIONS
FACING PAGE 02-00-1 <MST>

ACTION

Change '**OPERATING LIMITATIONS**' items to read as follows:

OPERATING LIMITATIONS

Altitude and Temperature Operating Limits	02–04–1
Take-off	02–04–2
Rotation Rate and Pitch Attitude	02–04–2
Pitch Trim	02–04–2
Take-off Pitch Target	02–04–2
Operation in Icing Conditions	02–04–2
Cowl Anti-ice System	02–04–2
Wing Anti-ice System	02–04–3
Thrust Settings	02–04–3
Super-Cooled Large Droplet Icing	02–04–3
Cold Weather Operations	02–04–4
Enhanced Take-off Procedures and Winter Operations Training	02–04–5
Runway Slopes	02–04–5
Tailwind Conditions	02–04–5
Minimum Flight Crew	02–04–5
Cargo	02–04–5
Maximum Occupants <0056>	02–04–5
Maximum Occupants <JCAB> <HKCAD>	02–04–6
Ozone Concentration <TC> <FAA> <JCAB>	02–04–6

INSERT IN LIMITATIONS - OPERATING LIMITATIONS
FACING PAGE 02-04-2

ACTION 1

Add the following new **"TAKE-OFF"** limitations:

2. TAKE-OFF

A. Rotation Rate and Pitch Attitude

WARNING

Excessive rotation rates (exceeding 3 degrees per second) or over-rotations may lead to high pitch attitudes and angles of attack being attained while the aircraft is near the ground. This can reduce stall margins significantly resulting in stick shaker / pusher activation and potentially loss of control. Pilots must rotate smoothly towards the target pitch attitude then transition to speed control.

B. Pitch Trim

WARNING

Failure to set the pitch trim appropriate to the computed centre of gravity may result in excessive rotation rate at take-off.

- Pitch trim must be set according to the airplane's computed centre of gravity.

Effectivity:

- *Airplanes **not incorporating** the −904 or the −037 Flight Control Computer:*

C. Take-Off Pitch Target

- The initial target for rotation is 10 degrees.
- If the flight director is used for take-off, set pitch target of 10 degrees. (Refer to Flight Crew Operating Manual, Volume 2 (CSP A-013): SUPPLEMENTARY PROCEDURES − Automatic Flight Control System − TAKE-OFF).
- Take-off performance data in Chapter 6 remains applicable.

ACTION 2

Change paragraph " **2. Operation in Icing Conditions**" to read " **3. Operation in Icing Conditions**"

INSERT IN LIMITATIONS - OPERATING LIMITATIONS
FACING PAGE 02-04-3

ACTION

Change paragraph **“B. Wing Anti-Ice System”** to read as follows:

B. Wing Anti-ice System

Ground Operations:

NOTE

Icing conditions exist on the ground when the OAT is 5°C (41°F) or below and:

- visible moisture in any form (such as clouds, fog or mist), is present below 400 feet AGL, or
- the runway is wet or contaminated, or
- in the presence of any precipitation (such as rain, snow, sleet or ice crystals).

Effectivity (Commencing 1 December, 2008):

- *Airplanes 7003 thru 8076, 8082, 8086, 8090 thru 8092, 8096 and 8097* ***not incorporating*** *Service Bulletin SB A601R–30–032, Ice and Rain Protection – Wing Anti-Ice System – Inspection of the Wing Anti-Ice Piccolo Tubes:*

- Take-off in icing conditions, which would require the use of the wing anti-ice system, is prohibited.

- The wing anti-ice system must be selected ON during final taxi prior to take-off if the OAT is 5°C (41°F) or below, unless Type II, Type III or Type IV anti-icing fluids have been applied. During single engine taxi operations, final taxi prior to take-off is defined as that period after the second engine is started.

NOTE

1. L or R WING A/ICE caution messages may be posted during taxi but must be verified out and WING A/ICE ON advisory message posted, prior to take-off. If wing anti-ice is not required for take-off, it should be selected OFF just prior to take-off.
2. To prevent wing contamination from reverse jet blast, operating the thrust reversers during taxi operations on wet and contaminated surfaces should be avoided.

B. Wing Anti-ice System (Cont'd)

- The wing anti-ice system must be selected and confirmed ON for take-off, when the OAT is 5°C (41°F) or below and:
  - visible moisture in any form (such as clouds, fog or mist), is present below 400 feet AGL, or
  - the runway is wet or contaminated, or
  - in the presence of any precipitation (such as rain, snow, sleet or ice crystals).

NOTE

If the wing anti-ice system is selected ON for take-off, the cowl anti-ice system must also be selected ON.

- When Type II, Type III or Type IV anti-icing fluids have been applied,the wing anti-ice system must only be selected and confirmed ON just prior to thrust increase for take-off.
- Refer to Flight Crew Operating Manual, Volume 2 (CSP A-013) SUPPLEMENTARY PROCEDURES – Cold Weather Operations – Phase of Flight Procedures.

Flight Operations:

NOTE

Icing conditions exist in flight at a **TAT** of 10°C (50°F) or below, and visible moisture in any form is encountered (such as clouds, rain, snow, sleet or ice crystals), except when the **SAT** is –40°C (–40°F) or below.

- The wing anti-ice system must be ON:
  - When ICE is annunciated by the ice detection system, or
  - When in icing conditions and the airspeed is less than 230 KIAS.

Effectivity (Commencing 1 December, 2008):

- *Airplanes 7003 thru 8076, 8082, 8086, 8090 thru 8092, 8096 and 8097* ***not incorporating*** *Service Bulletin SB A601R–30–032, Ice and Rain Protection – Wing Anti-Ice System – Inspection of the Wing Anti-Ice Piccolo Tubes:*
  - Continued flight in conditions requiring the use of wing anti-ice is prohibited.
  - If the wing anti-ice system was selected ON in flight, leave icing conditions, and
    - If the visible portion of the wings can be confirmed, from the cockpit, to be free of ice and the TAT for approach and landing is greater than 10°C, accomplish a normal approach and landing.
    - If the visible portion of the wings cannot be confirmed, from the cockpit, to be free of ice or the TAT for approach and landing is less than or equal to 10°C, accomplish ABNORMAL PROCEDURES, Ice and Rain Protection, Wing Anti-Ice Piccolo Duct Damage Suspected Procedure.

INSERT IN LIMITATIONS - OPERATING LIMITATIONS
AS NEW PAGE 02-04-4

4. COLD WEATHER OPERATIONS

WARNING

Even small amounts of frost, ice, snow or slush on the wing leading edges and forward upper wing surface may adversely change the stall speeds, stall characteristics and the protection provided by the stall protection system, which may result in loss of control on take-off.

A. Take-off is prohibited with frost, ice, snow or slush adhering to any critical surface, (wings, upper fuselage, horizontal stabilizer, vertical stabilizer, control surfaces and engine inlets).

NOTE

1. Take-off is permitted with frost adhering to:
   - the upper surface of the fuselage; and/or
   - the underside of the wing, that is caused by cold soaked fuel,

   in accordance with the instructions provided in Flight Crew Operating Manual, Volume 2 (CSP A-013) SUPPLEMENTARY PROCEDURES – Cold Weather Operations – Pre-flight Preparation, External Safety Inspection.
2. Comprehensive procedures for operating in cold weather are provided in Flight Crew Operating Manual, Volume 2: (CSP A-013), SUPPLEMENTARY PROCEDURES – Cold Weather Operations.

B. In addition to a visual check, a tactile check of the wing leading edge, wing forward upper surface and wing rear upper surface is required during the External Walkaround inspection to determine that the wing is free from frost, ice, snow or slush when:

(1) the Outside Air Temperature (OAT) is 5°C (41°F) or less, or

(2) the wing fuel temperature is 0°C (32°F) or less; or

(3) the atmospheric conditions have been conducive to frost formation.

NOTE

Ice and frost may continue to adhere to wing surfaces for some time even at outside air temperatures above 5°C (41°F).

INSERT IN LIMITATIONS - OPERATING LIMITATIONS
AS NEW PAGE 02-04-5 <MST>

4A. ENHANCED TAKE-OFF PROCEDURES AND WINTER OPERATIONS TRAINING

The limitations in this paragraph are effective commencing 1 November, 2008.

No take-off shall be conducted where the OAT is 5°C (41°F) or below, unless the pilot-in-command has successfully completed specific training, within the preceding 12 calendar months, for take-off procedures, ground icing conditions and cold weather operations.

No take-off shall be conducted by a pilot where the OAT is 5°C (41°F) or below, unless that pilot has successfully completed the specific training, within the preceding 12 calendar months, for take-off procedures, ground icing conditions and cold weather operations.

If neither of the preceding requirements has been complied with, the wing anti-ice system must be selected ON for take-off, just prior to thrust increase for take-off, if the OAT is 5°C (41°F) or below.

Completion of the following Bombardier Aerospace course will meet the intent of this training requirement:

- Bombardier Aerospace Enhancement to Take-Off Operational Safety Margins Training.

5. RUNWAY SLOPES

The maximum runway slopes approved for take-off and landing are:

+2% (uphill)
−2% (downhill)

6. TAILWIND CONDITIONS

The maximum tailwind component approved for take-off and landing is 10 knots.

7. MINIMUM FLIGHT CREW

The minimum flight crew is one pilot and one copilot.

8. CARGO

Flight must be within 60 minutes of a suitable airport, if cargo is carried in the cargo compartment. <0053> <0074>

Flight must be within 40 minutes of a suitable airport <0013><0059><British European>
(45 minutes of a suitable airport <0034><0043>), if cargo is carried in the cargo compartment.

Both smoke detectors must be operational, if cargo is carried in the cargo compartment. <British European>

Carriage of cargo is prohibited. <0057>

Items / articles not essential to the ferry operation shall not be carried in the cargo compartment or cabin area. <0057>

9. MAXIMUM OCCUPANTS <0056>

The total number of occupants, including no more than nineteen passengers, must not exceed the lesser of the following:

- Twenty-two or,
- The number for which seating accommodation approved for take-off and landing is provided.

AEROSPACE

BOMBARDIER

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FLIGHT OPERATIONS NOTE

CRJ Pilot Liaison In-Service Engineering & Technical Support

CRJ100/200/440, CL 850-FON-00-004

ATA: 0000

DATE: 19 March, 2008

SUBJECT: Takeoff Safety Enhancements

MODEL: CL-600-2B19 (CRJ100/CRJ200/CRJ440/Challenger 850)

APPLICABILITY: All

Ref: Transport Canada AD CF-2008-15
AFM TR RJ/155-2

PURPOSE:

The purpose of this document is to provide clarification about the reasons for and operational impacts of the new limitations and procedures associated with the reference AD and Temporary Revision to the AFM

DISCUSSION:

Following three recent accidents/incidents where Bombardier CL-600-2B19/CL-600-2B16 aircraft experienced un-commanded roll during take–off, it has been deemed necessary to further enhance the AFM limitations and procedures to ensure safe operation, particularly in cold weather or icing conditions. This initiative must be seen as a means of enhancing the aircraft's take-off safety margins to compensate for potential human error. The major factors that have been identified in each of these events are discussed below.

The first and most obvious factor in many of these events was attempted takeoff with contamination on the aircraft's critical surfaces; especially the wing leading edge. The CRJ, Challenger 850 and Challenger 600 series of aircraft wing designs are such that any disruption of airflow over the wing leading edge area will significantly reduce the angle of attack at which the wing stalls. Any amount of wing leading edge contamination can cause such disruption. In the worst case this can result in an aerodynamic stall of the wing and uncommanded roll at or shortly after lift-off. The new limitations and procedures are designed to further highlight the need for proper preflight inspections and de-icing/anti-icing of the critical surfaces as they currently exist. This is mandatory. The use of wing anti-ice during certain specified taxi operations is intended to further ensure that the leading edge remains clean prior to takeoff. The changes to the takeoff limitations for use of wing anti-ice are designed to cater to a more comprehensive range of conditions under which ice may form.

The second factor that has been implicated in these events was an improper rotation technique. In many cases, the aircraft was rotated aggressively, well above the recommended 2 to 3 degree per second rotation rate, or was rotated before the scheduled Vr. Rapid or early rotation reduces aerodynamic margins and may become a hazard when combined with other factors such as wing contamination. Data collected during testing of a modified flight director system indicated that lowering the target pitch attitudes has the beneficial effect of decreasing the pilot's tendency to rotate aggressively. This in turn can significantly reduce the maximum angle-of-attack during takeoff and thus improve the margin to the aerodynamic stall.

BOMBARDIER ACTION:

Bombardier has issued Temporary Revision RJ/155-2 which addresses the concerns and solutions outlined above. The highlights of the changes are:

1. Redefine the criteria for "Ground Icing Conditions". Under the new definition, one major change is that visibility criteria have been removed. This is designed to "catch" conditions where contamination may form, but not be covered by the old definition. The new definition of ground icing conditions now reads:

   NOTE

   Icing conditions exist on the ground when the OAT is 5°C (41°F) or below and:

   - Visible moisture in any form (such as clouds, fog or mist), is present below 400 feet AGL, or
   - The runway is wet or contaminated, or
   - In the presence of any precipitation (such as rain, snow, sleet or ice crystals).

2. Introduce a requirement for the wing anti-icing system to be selected ON during final taxi prior to takeoff, if the OAT is 5°C or below, unless Type II, III, or IV anti-icing fluids have been applied. There is no need to ensure that the wing is fully heated (as indicated by WING A/I ON advisory messages) for the entire taxi, only

that the advisory message be posted prior to takeoff. The intention of this change is to change the philosophy of wing anti-ice use from one where the anti-ice is only selected "ON" if needed to one where the anti-ice is normally selected on, and only selected "OFF" if conditions permit. There is no need to have wing anti-icing selected on for manoeuvring (such as prior to de-icing or cross bleed start), only for the final taxi to the runway. Procedures are also given for single engine taxi. The requirement remains unchanged to leave wing anti-icing off where the aircraft has been anti-iced with Type II, III, or IV fluids.

Flight crews should be reminded that if wing anti-ice is selected on and cowl anti-ice is left off, that no takeoff thrust indication will be posted, as this is not considered to be a valid bleed configuration for takeoff. Valid anti-ice configurations for takeoff are cowl ant-ice on, wing and cowl anti-ice on, or all off.

If Operators are using Bombardier recommended procedures in their present checklists, the impact of this will be fairly minor. Flight crews will select the anti-ice on during the "After Start" checklist, and may under some conditions select wing anti-icing off when it comes up again in the "Before Takeoff" checklist. It should also be noted that there is no time limit for the use of wing anti-ice on the ground for the CL 600-2B19. The wings will not overheat as the temperature is controlled at preset limits based on wing leading edge temperature.

3. The wing anti-ice system must be selected on for takeoff when Ground Icing Conditions exist. While this will increase the number of takeoffs where this is required, it will also ensure that no ice or frost will adhere to the leading edge in cases that might not otherwise be caught. The intention is to be more conservative in deciding when to use the wing anti-ice system, while at the same time reducing the opportunities for pilot errors. It is anticipated that the number of additional takeoffs where the wing anti-ice is required will not increase significantly with the new requirement.

4. The conditions under which a tactile inspection of the wing is required have become broader. Since this is a simple and fast check it should be much easier for flight crew to understand and comply with.

5. Bombardier and Transport Canada been made aware that some Operators have, in creating their customized "Pilot's Checklists", removed one or both of the challenges to activate the anti ice systems on the ground as directed by the AFM. The AD instructs Operators to ensure that anti ice challenges are included in the Operators checklists as per the AFM. Checklists should challenge the flight crew to assess the need for anti ice system activation both "After Start" and again "Before Takeoff".

6. Warnings against high rotation rates (defined as exceeding 3° per second) and over rotations have been introduced along with description of the consequences of incorrect rotation.

7. For aircraft not incorporating the -904 or the -037 Flight Control Computers (FCC's), the initial target for rotation must be manually set to 10°. The suggested method for setting the flight director to 10° is to press TOGA and then use the pitch wheel to obtain a pitch setting of 10°. Movement of the pitch wheel after

pressing the TOGA switch will result in the FMA reading TO/PTCH. There is no loss of functionality of the flight directors by using this procedure, since the vertical component of Takeoff Mode is simply PTCH Mode with a pitch value pre-determined by the FCC. This procedure described above provides similar guidance to Takeoff Mode, except for the automatic drop of the director to 10° in the event of an engine failure. By setting the pitch to 10°, this issue is not applicable. It should be noted that the takeoff mode of the Autothrottle System (ATS) will not function if this procedure is accomplished. ATS will function normally after takeoff.

The remainder of the takeoff procedure is unchanged. Flight crew should still rotate towards the target pitch attitude, then transition to speed (i.e. CLB or IAS mode) immediately after initial rotation. Speed may then be adjusted as required for the initial climb. This procedure has been deemed to meet performance requirements, while at the same time providing an appropriate initial target in the case of engine failure.

In the long term, the target pitch attitude for initial rotation will become 12°. The vertical component of Takeoff Mode for the -904 or the -037 Flight Control Computers is already set at 12°, but this is a relatively small portion of the fleet. Bombardier will be initiating an aggressive plan in the coming months to upgrade the entire fleet to the newer flight directors by providing the hardware upgrade free of charge.

OPERATOR ACTION:

Operators should make their flight crew aware of the new limitations and procedures described here. It is strongly recommended that Operators review their cold weather operations procedures and training programs. Operators must ensure that all flight crews are made properly aware of the necessity to ensure that the wings on all aircraft are completely free of contamination prior to takeoff, and of the need to adhere to normal rotation rates.

Bombardier has provided a free online Icing Awareness training course, on the RACS website (http://www.racs.bombardier.com/), and encourages all people involved with flight operations to take the time to complete this course in the near future. No login is required to take the course, and the course material may also be obtained free of charge on CD form through the same site. Bombardier has committed to supporting operators in any reasonable way possible in the development and refining of their cold weather operations training programs. It is anticipated that a further AD will be issued in the coming months which will mandate icing awareness training for flight crews. Bombardier is working with TCCA and will work with airlines to ensure that implementation of this is done as smoothly and efficiently as possible.

Please direct responses and inquiries to your Bombardier Aerospace Regional Aircraft Field Service Representative or the Technical Help Desk in Montreal at telephone number (514) 855-8500 or facsimile (514) 855-8501 or e-mail: thd.crj@aero.bombardier.com.

Original signature on file	Original signature on file
Andrew Gardiner	Andrew Palmer
CRJ Customer Liaison Pilot	Engineering – Stability & Control

The Estimation of Snowfall Rate Using Visibility

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(Manuscript received 17 February 1998, in fina form 29 September 1998)

ABSTRACT

The relationship between liquid equivalent snowfall rate and visibility is investigated using data collected at the National Center for Atmospheric Research Marshall Snowfall Test Site during two winter fiel seasons and using theoretical relationships. The observational data include simultaneous liquid equivalent snowfall rate, crystal types, and both automated and manual visibility measurements. Theoretical relationships between liquid equivalent snowfall rate and visibility are derived for 27 crystal types, and for ''dry'' and ''wet'' aggregated snowflakes Both the observations and theory show that the relationship between liquid equivalent snowfall rate and visibility depends on the crystal type, the degree of riming, the degree of aggregation, and the degree of wetness of the crystals, leading to a large variation in the relationship between visibility and snowfall rate. Typical variations in visibility for a given liquid equivalent snowfall rate ranged from a factor of 3 to a factor of 10, depending on the storm. This relationship is shown to have a wide degree of scatter from storm to storm and also during a given storm. The main cause for this scatter is the large variation in cross-sectional area to mass ratio and terminal velocity for natural snow particles.

It also is shown that the visibility at night can be over a factor of 2 greater than the visibility during the day for the same atmospheric extinction coefficient Since snowfall intensity is define by the U.S. National Weather Service using visibility, this day/night difference in visibility results in a change in snowfall intensity category caused by only whether it is day or night. For instance, a moderate snowfall intensity during the day will change to a light snowfall intensity at night, and a heavy snowfall intensity during the day will change to a moderate snowfall intensity at night, for the same atmospheric extinction coefficient

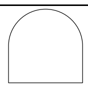
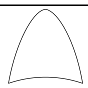
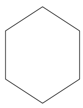
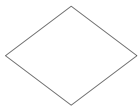
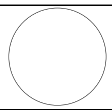
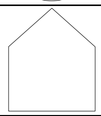
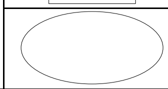
Thus, the standard relationship between snowfall intensity and visibility used by many national weather services (1/4 mile or less visibility corresponds to heavy snowfall intensity, between 5/16 and 5/8 mile corresponds to moderate intensity, and greater than 5/8 mile corresponds to light intensity) does not always provide the correct indication of actual liquid equivalent snowfall rate because of the variations in snow type and the differences in the nature of visibility targets during day and night. This false indication may have been a factor in previous ground-deicing accidents in which light snow intensity was reported based on visibility, when in fact the actual measured liquid equivalent snowfall rate was moderate to heavy.

Feiltreanalyse /Fault Tree Analysis

Feiltreanalyse (FTA) er en vanlig analysemetode i risiko- og pålitelighetsanalyser, og er mye brukt innen petroleum og kjernekraft. Feiltreanalyse kan brukes til å bestemme årsakene til en uønsket hendelse og til å finne sannsynligheten eller frekvensen til denne hendelsen. Det er utarbeidet flere standarder og retningslinjer for feiltreanalyse. Et feiltre består av symboler som viser inngangshendelsene i systemet, og sammenhengen mellom disse inngangs-hendelsene og topp-hendelsen. De grafiske symboler som viser sammenhengene, kalles logiske porter. Utgangen av en logisk port er bestemt av inngangshendelse (Rausand og Utne, 2009).

I denne undersøkelsen er feiltremetodikken brukt for å få en logisk oversikt over kombinasjoner av hendelser og avvik som medvirker til en spesifikk uønsket hendelse. Topp-hendelsen er i dette tilfellet definert som "premature wing stall".

Følgende feiltresymboler er brukt i analysen:

Symboler for logiske porter		**AND** – utgangshendelsen inntreffer bare hvis samtlige inngangshendelser inntreffer.
		**OR** – utgangshendelsen inntreffer dersom minst én av inngangshendelsene inntreffer.
		**INHIBIT** – utgangshendelsen inntreffer dersom inngangshendelsen inntreffer ved tilstedeværelsen av en betingelse (betingelsen representeres av en betingende hendelse til høyre for porten).
Symboler for inngangshendelser		**Intermediær hendelse** – en hendelse som inntreffer fordi en eller flere foregående hendelser virker gjennom logiske porter.
		**Ikke utviklet hendelse –** en hendelse som ikke utvikles videre fordi den er av utilstrekkelig konsekvens eller fordi informasjon ikke er tilgjengelig.
		**Basis hendelse** – en basis initierende hendelse som ikke krever videre utvikling.
		**Ekstern hendelse –** en hendelse som normalt er forventet å inntreffe.
		**Betingende hendelse –** spesifikk betingelse eller restriksjon som gjelder for en logisk port

Referanser:

M. Rausand og I. B. Utne (2009): *Risikoanalyse – teori og metoder.* Tapir Akademisk Forlag, Trondheim.

NUREG-0492 (1981): *Fault Tree Handbook.* U.S. Nuclear Regulatory Commission, Washington D.C.

NASA (2002): Fault Tree Handbook with Aerospace Applications. NASA Office of Safety and Mission Insurance, Washington D.C.

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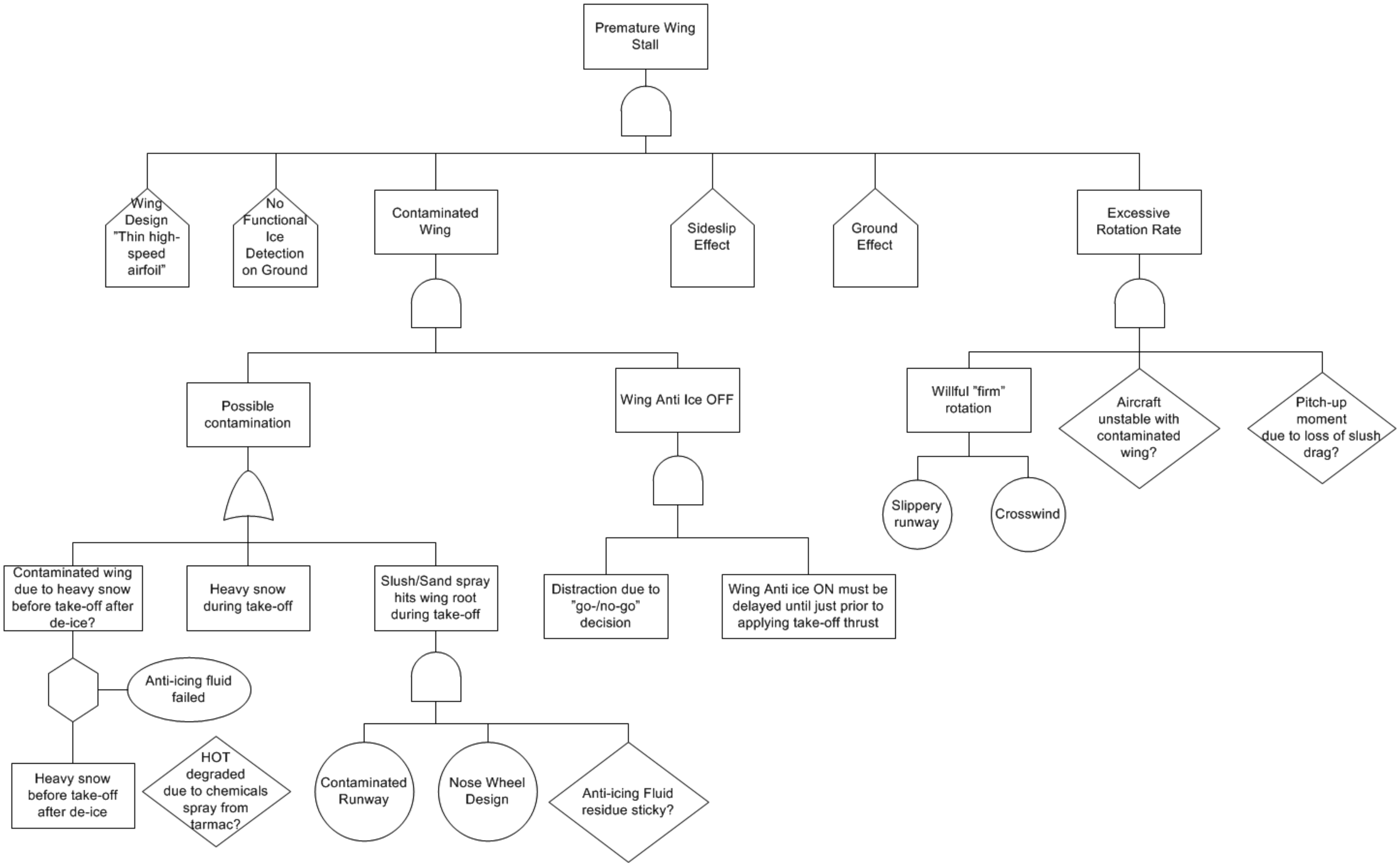

Barrier Analysis Worksheet – Adapted from Department of Energy (DOE), USA

Hazard: Contamination from precipitation and RWY surface			*Target: Wing leading edge/upper surface contamination reducing stall margins*			
What were the barriers/ which were missing?	*How did each barrier perform?*	*Why did the barrier fail?*	*How did the barrier affect the incident?*	*Safety Action Taken*	*(Further) corrective actions needed?*	*Priority*
De-/Anti-icing	De-/Anti-icing performed according to procedures.			New guidelines given on when de-/anti-icing is required and enhanced procedures provided	No	
Met reports	Precipitation intensity reported according to procedures, based on visibility.	High water content in huge, wet snow flakes. No information available for flight crew to verify this hazard, since visibility reduction indicated moderate snow intensity.	HOT guidelines may not have been valid. Possible fluid failure due to heavy snow? Fluid flows off leading edge first. Sticky, wet snow flakes may have covered the wing leading edge and upper surface at take-off.	None	Yes. North American guidelines for visibility versus precipitation intensity are more conservative than the Norwegian ones.	3
Snow clearing	Snow clearing performed 30 min before take-off. Runway sanded. Continuous precipitation.	Actual slush depth/wet snow depth not monitored/ measured.	Actual slush/wet snow depth on runway may have been close to or above limit for take-off.	None		
Wing Anti-Ice ON	Wing Anti-Ice unintentionally OFF during take-off.	According to procedures, WAI selection ON must be delayed to just prior to take-off due to preservation of anti-icing fluid. Pilot was distracted and forgot to turn WAI ON, no reminder/ warning system exists.	Wing leading edge contamination worsened and stall margin was lost.	- Crew training requirements - Changed parameters for when WAI ON is required	Yes. Critical safety issue.	1

Cont.

What were the barriers/ which were missing?	*How did each barrier perform?*	*Why did the barrier fail?*	*How did the barrier affect the incident?*	*Safety Action Taken*	*(Further) corrective actions needed?*	*Priority*
Slush spray prevention	Missing barrier – No barrier exists that protects the wing from a continuous slush spray from the nose wheel during take-off roll, until the nose wheel leaves the ground at rotation.		Slush spray from the nose wheel hit the wing root area and leading edge spanwise to the "kink" area, reducing stall margin and disturbing lift generation at wing root.	None. Threat hardly mentioned in aircraft documentation.	Yes	2
Wing contamination warning	Missing barrier – The thin high-speed airfoil is sensitive to leading edge/ upper surface contamination. No barrier exists that warns about wing contamination while the aircraft is on ground.		Take-off commenced with contaminated wings.	None	Yes. Recommendation already exists.	2

Barrier Analysis Worksheet – Adapted from Department of Energy (DOE), USA

Hazard: Excessive rotation rate close to the ground *Target: Wing leading edge stall – when wing leading edge/upper surface is contaminated*

What were the barriers and possible missing barriers?	*How did each barrier perform?*	*Why did the barrier fail?*	*How did the barrier affect the incident?*	*Safety Action Taken*	*(Further) corrective actions needed?*	*Priority*
Procedures describing maximum rotation rate 3 degrees per second.	The procedure did not prevent the Pilot Flying (PF) from performing a "firm" take-off.	PF desire to get airborne from slippery runway in crosswind. Not aware of contaminated wings and the associated high risk level. No indication of rotation rate presented in cockpit.	Aircraft obtained high angle of attack close to the ground, where stall margins are lowered due to ground effect and sideslip.	- AD Note with training requirements - Flight Director pitch command bar lowered from 15 to 12 degrees. - Cimber Sterling intend to implement FOQA	No	
Missing barrier – Pitch rate monitoring	No indication of pitch rate in cockpit.			None	No	
Pilot Monitoring (PM)	PM observed high initial rotation rate, but no interference was required since it was immediately corrected by the Pilot Flying (PF).	It happened very fast.	No effect	None	No	
Procedures to ensure aircraft stability and control	Centre of gravity correctly calculated within limits, trim setting correct.	Possible moment changes due to centre of pressure change on contaminated wing and/or change in (loss of) slush drag at rotation.	Unknown	None	Unknown	

Transport Canada comments for the Accident Investigation Board Norway (AIBN) regarding the draft Aviation Investigation Report 08/68-34 (TSB # A08F0020) involving the Cimber Air Denmark, stick shaker after takeoff incident involving the Canadair CL600-2B19 (CRJ200), registration OY-RJC at Oslo Airport Gardermoen, Norway 31 January 2008

Page 31, Figure 12, Photo from the Water Ingestion Test

This dramatic picture of a regional jet undergoing water injection trials is misleading, as it is not representative of the scenario on the night of January 31. The implication is OY-RJC faced a similar slush/ water spray pattern from the nose wheel.

Transport Canada suggests that it would add value to the report if figure 12 was removed from the report.

Analysis

Page 39, Section 2.1.1

The report states, "The AIBN asserts that it is nowadays uncommon that an aircraft type used in regular transport of passengers is involved in so many accidents and incidents with clear common characteristics."

This statement is basically anecdotal with no supporting data other than the listing (page 34) of 10 accidents over 13 years including three aircraft being a different Bombardier model. This statement would require considerably more data categorised "aircraft type used in regular transport of passengers", in order to analyse and substantiate the referenced conclusion.

Transport Canada suggests the AIBN may wish to remove the referenced statement.

Page 50, Recommendation 2010/aaT

Transport Canada acknowledges, "that contaminated leading edges on aircraft of the CL-600 series during take-off can cause premature stall with an uncontrollable wing drop and a risk of a catastrophic outcome" if the flight crew does not follow the procedures in the Aircraft Flight Manual (AFM). The AIBN uses a Sequential Time Events Plotting (STEP) diagram to prioritise the safety items and has further determined the type of corrective action through this recommendation. This recommendation, restricting the regulator and the product manufacturer to non-procedural corrective action, is unacceptable to the Department.

Transport Canada suggests the AIBN may wish to remove the restriction imposed by the recommendation.

Page 50, Safety Recommendation 2010/bbT

This recommendation has already been implemented via the Take-off Safety Enhancement program. This incident was primarily due to the crew not turning on the WAI during the take-off roll when it was clearly required by the existing AFM Limitations. The excessive bleed air available on take-off is more than sufficient to deal with the spray from a contaminated runway when the WAI is selected on. If it were not so, there would have been far more incidents involving take-offs from contaminated runways.

Transport Canada is satisfied with the safety enhancements now in place however, the Department will continue to work with Bombardier to improve CL-600 series safety margins.

.../2

Page 51, Safety Recommendation 2010/ccT
While Transport Canada may agree with this recommendation to explore better solutions for diverting the spray (redesign of nose wheel chines), this is not an issue specific to the CRJ200. This issue is generic to all low wing aircraft regardless of manufacture.

Transport Canada recommends the AIBN expand this recommendation to include all low wing aircraft and associated Civil Aviation Authorities.