Statens haverikommission
Swedish Accident Investigation Authority

Final report RL 2016:11e

Accident in Oajevágge, Norrbotten County, Sweden on 8 January 2016 involving the aeroplane SE-DUX of the model CL-600-2B19, operated by West Atlantic Sweden AB.

File no. L-01/16

12/12/2016

SHK investigates accidents and incidents from a safety perspective. Its investigations are aimed at preventing a similar event from occurring in the future, or limiting the effects of such an event. The investigations do not deal with issues of guilt, blame or liability for damages.

The report is also available on SHK´s web site: www.havkom.se

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This document is a translation of the original Swedish report. In case of discrepancies between this translation and the Swedish original text, the Swedish text shall prevail in the interpretation of the report.

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General observations

The Swedish Accident Investigation Authority (Statens haverikommission – SHK) is a state authority with the task of investigating accidents and incidents with the aim of improving safety. SHK accident investigations are intended to clarify, as far as possible, the sequence of events and their causes, as well as damages and other consequences. The results of an investigation shall provide the basis for decisions aiming at preventing a similar event from occurring in the future, or limiting the effects of such an event. The investigation shall also provide a basis for assessment of the performance of rescue services and, when appropriate, for improvements to these rescue services.

SHK accident investigations thus aim at answering three questions: *What happened? Why did it happen? How can a similar event be avoided in the future?*

SHK does not have any supervisory role and its investigations do not deal with issues of guilt, blame or liability for damages. Therefore, accidents and incidents are neither investigated nor described in the report from any such perspective. These issues are, when appropriate, dealt with by judicial authorities or e.g. by insurance companies.

The task of SHK also does not include investigating how persons affected by an accident or incident have been cared for by hospital services, once an emergency operation has been concluded. Measures in support of such individuals by the social services, for example in the form of post crisis management, also are not the subject of the investigation.

Investigations of aviation incidents are governed mainly by Regulation (EU) No 996/2010 on the investigation and prevention of accidents and incidents in civil aviation and by the Accident Investigation Act (1990:712). The investigation is carried out in accordance with Annex 13 of the Chicago Convention.

The investigation

SHK was informed on 08/01/2016 that an accident involving one aircraft with the registration SE-DUX had occurred in Oajevágge, Norrbotten County, on the same day at 00:20 hrs.

The accident has been investigated by SHK represented by Mr Jonas Bäckstrand, Chairperson, Mr Nicolas Seger, Investigator in Charge, Mr Sakari Havbrandt, Technical-operational Investigator, Mr Johan Nikolaou, Operations Investigator, Mr Tony Arvidsson, Mr Christer Jeleborg and Mr Ola Olsson, Technical Investigators and Mr Jens Hjortensjö, Investigator Behavioural Science until 23 September 2016, thereafter Mr Alexander Hurtig.

The investigation has been assisted by Ms Annika Wallengren as expert in the rescue services, Mr Kristoffer Danèl as an expert in aviation mechanics, Ms Liselotte Yregård as an expert in aviation medicine and Mr Ola Eiken and Mr Arne Tribukait as experts in environmental physiology.

The following countries' accredited representatives from respective safety investigations authorities have participated:

Canada, Brad Vardy, TSB (Transportation Safety Board of Canada).

France, Philippe Roblin, BEA (Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile).

Norway, Birger Bull, SHT (Statens havarikommisjon for transport).

Spain, Francisco-Javier Hernández Sanz, CIAIAC (Comisión de Investigación de Accidentes e Incidentes de Aviación Civil).

United States, Bill English, NTSB (National Transportation Safety Board).

The accredited representative of Canada has been assisted by advisors from Transport Canada and Bombardier Aerospace.

The accredited representative of the United States has been assisted by advisors from the Federal Aviation Administration (FAA), Rockwell Collins, Northrop Grumman, Honeywell and General Electric.

Mr Apostolos Batategas and Mr Alessandro Cometa from the European Aviation Safety Agency (EASA) have participated as advisors.

Mr Jan Eriksson and Mr Mats Ersbrant from the Swedish Transport Agency (Transportstyrelsen) have participated as advisors.

The following organisations have been notified: International Civil Aviation Organisation (ICAO), EASA, EU-Commission, BEA, TSB, SHT, NTSB, CIAIAC and the Swedish Transport Agency.

Investigation material

The aircraft's CVR[1] and DFDR[2] and approximately 3.5 tons of wreckage and 1 ton of mail have been recovered.

Another 9.5 tons of wreckage and mail have been examined at the accident site.

A fuel sample from the refuelling station at Oslo/Gardermoen Airport has been analysed.

A report concerning the de-icing fluids used during de-icing before take-off has been recovered.

Five CCTV recordings from the departure airport have been recovered and analysed.

[1] CVR – Cockpit Voice Recorder.
[2] DFDR – Flight Data Recorder.

Interviews have been conducted with loading and fuelling personnel as well as with the operator's management and pilots.

Radar information from civilian and military Norwegian and Swedish radar stations have been recovered.

Communication recordings between ATS and the flight crew have been recovered.

Meetings with representatives from TSB, Transport Canada, Bombardier, NTSB, FAA, Rockwell Collins, Northrop Grumman and Honeywell were held in Montreal, Canada during May 2016 and in Stockholm, Sweden during September 2016. During the Stockholm meeting representatives from BEA, CIAIAC, SHT and the Swedish Transport Agency participated.

A factual information meeting with the victims' families was held on 18 August 2016 and with other stakeholders on 14 September 2016. At the meetings SHK presented the facts collected during the investigation, which were available at the time.

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Aircraft:	
Registration, type	SE-DUX, CRJ200
Model	CL-600-2B19
Class, Airworthiness	Normal, Certificate of Airworthiness and Valid Airworthiness Review Certificate (ARC[3])
Serial number	7010
Operator	West Atlantic Sweden AB
Time of occurrence	8 January 2016, 00:20 hrs during darkness Note: All times are given in Swedish standard time (UTC[4] + 1 hour)
Place	Oajevágge, Norrbotten County, Sweden (position 6743N 01654E, 2 370 feet above mean sea level)
Type of flight	Commercial Air Transport
Weather	According to SMHI's analysis: At FL330: wind northwest 30 knots, visibility >10 kilometres, no clouds, temperature -60 to -63°C At the accident site: wind light and variable, visibility >10 kilometres, no clouds, temperature -20 to -25°C, dew point -30°C, QNH[5] 1010 hPa
Persons on board:	2
crew members including cabin crew	2
passengers	None
Injuries to persons	2 fatally injured
Damage to aircraft	Destroyed
Other damage	Damage to terrain, fuel and oil spill
Pilot in command:	
Age, licence	42 years, ATPL(A)[6]
Total flying hours	3 365 hours, of which 2 208 hours on type
Flying hours previous 90 days	130 hours, all on type
Number of landings previous 90 days	93
Co-pilot:	
Age, licence	33 years, CPL(A)[7]
Total flying hours	3 232 hours, of which 1 064 hours on type
Flying hours previous 90 days	130 hours, all on type
Number of landings previous 90 days	94

[3] ARC – Airworthiness Review Certificate.
[4] UTC - Coordinated Universal Time is a reference for the exact time anywhere in the world.
[5] QNH - Barometric pressure reduced to mean sea level.
[6] ATPL(A) - Airline Transport Pilot License Aeroplane.
[7] CPL(A) - Commercial Pilot License Aeroplane.

SUMMARY

The accident occurred on 8 January 2016 during a commercial cargo flight from Oslo/Gardermoen Airport (ENGM) to Tromsø/Langnes Airport (ENTC) and involved an aeroplane of the model CL-600-2B19, manufactured by Bombardier Inc. The aeroplane was operated by West Atlantic Sweden AB and had the registration SE-DUX.

The flight was uneventful until the start of the event, which occurred during the approach briefing in level flight at FL 330. The event started at 00:19:20 hrs during darkness without moonlight, clouds or turbulence. The lack of external visual references meant that the pilots were totally dependent on their instruments which, inter alia consisted of three independent attitude indicators.

According to recorded data and simulations a very fast increase in pitch was displayed on the left attitude indicator. The pilot in command, who was the pilot flying and seated in the left seat exclaimed a strong expression. The displayed pitch change meant that the pilot in command was subjected to a surprise effect and a degradation of spatial orientation The autopilot was, most probably, disconnected automatically, a "cavalry charge" aural warning and a single chime was heard, the latter most likely as a result of miscompare between the left and right pilots' flying displays (PFD).

Both elevators moved towards nose down and nose down stabilizer trim was gradually activated from the left control wheel trim switch. The aeroplane started to descend, the angle of attack and G-loads became negative. Both pilots exclaimed strong expressions and the co-pilot said "come up".

About 13 seconds after the start of the event the crew were presented with two contradictory attitude indicators with red chevrons pointing in opposite directions. At the same time none of the instruments displayed any comparator caution due to the PFDs declutter function in unusual attitude.

Bank angle warnings were heard and the maximum operating speed and Mach number were exceeded 17 seconds after the start of the event, which activated the overspeed warning.

The speed continued to increase, a distress call was transmitted and acknowledged by the air traffic control and the engine thrust was reduced to flight idle.

The crew was active during the entire event. The dialogue between the pilots consisted mainly of different perceptions regarding turn directions. They also expressed the need to climb. At this stage, the pilots were probably subjected to spatial disorientation. The aircraft collided with the ground one minute and twenty seconds after the initial height loss.

The two pilots were fatally injured and the aeroplane was destroyed.

SHK has investigated the alerting and rescue services that were performed. There is a potential for improvement of procedures, training and exercises that could shorten the alerting time, improve the situational awareness of relevant

rescue authorities and increase the ability to carry out a rescue operation in the mountains.

The accident site and the wreckage did not show any evidence of an inflight break-up.

The flight recorders were recovered and readout. Calculations and simulations were performed to reconstruct the event and showed that the aeroplane's flight control system operated normally.

The erroneous attitude indication on PFD 1 was caused by a malfunction of the Inertial Reference Unit (IRU 1). The pitch and roll comparator indications of the PFDs were removed when the attitude indicators displayed unusual attitudes. In the simulator, in which the crew had trained, the corresponding indications were not removed. During the event the pilots initially became communicatively isolated from each other.

The current flight operational system lacked essential elements which are necessary. In this occurrence a system for efficient communication was not in place. SHK considers that a general system of initial standard calls for the handling of abnormal and emergency procedures and also for unusual and unexpected situations should be incorporated in commercial aviation.

The accident was caused by insufficient operational prerequisites for the management of a failure in a redundant system.

Contributing factors were:

- The absence of an effective system for communication in abnormal and emergency situations.
- The flight instrument system provided insufficient guidance about malfunctions that occurred.
- The initial manoeuver that resulted in negative G-loads probably affected the pilots' ability to manage the situation in a rational manner.

Safety recommendations

ICAO is recommended to:

- Ensure that a general system of initial standard calls for the handling of abnormal and emergency procedures and also for unusual and unexpected situations is implemented throughout the commercial air transport industry. *(RL 2016:11 R1)*

EASA is recommended to:

- Ensure that a general system of initial standard calls for the handling of abnormal and emergency procedures and also for unusual and unexpected situations is implemented throughout the commercial air transport industry. *(RL 2016:11 R2)*

- Ensure that the design criteria of PFD units are improved in such a way that pertinent cautions are not removed during unusual attitude or declutter modes. *(RL 2016:11 R3)*

Transport Canada is recommended to:

- Ensure that a general system of initial standard calls for the handling of abnormal and emergency procedures and also for unusual and unexpected situations is implemented throughout the commercial air transport industry. *(RL 2016:11 R4)*

- Ensure that the design criteria of PFD units are improved in such a way that pertinent cautions are not removed during unusual attitude or declutter modes. *(RL 2016:11 R5)*

FAA is recommended to:

- Ensure that a general system of initial standard calls for the handling of abnormal and emergency procedures and also for unusual and unexpected situations is implemented throughout the commercial air transport industry. *(RL 2016:11 R6)*

- Ensure that the design criteria of PFD units are improved in such a way that pertinent cautions are not removed during unusual attitude or declutter modes. *(RL 2016:11 R7)*

The Swedish Transport Agency is recommended to:

- Ensure that providers of air traffic control units guarantee procedures to enable an alerting message about a critical situation to be submitted immediately to the air rescue centre concerned. *(RL 2016:11 R8)*

- Ensure that providers of air traffic control units train and exercise relevant personnel so that they can assist the air rescue centre in accordance with current regulations. *(RL 2016:11 R9)*

- Ensure that the Maritime Administration secures that all crews maintaining preparedness for SAR missions in mountainous areas fulfil the requirements on capability to perform appropriate search tasks. *(RL 2016:11 R10)*

The Swedish Maritime Administration is recommended to:

- Develop the coordination between the sea and air rescue coordination centre (JRCC) and concerned air traffic control units (including ATCC) so that air traffic control units' staff becomes familiar with which facts and other information they may need to assist JRCC. *(RL 2016:11 R11)*

- Ensure that rescue commanders and assistant rescue commanders are given regular training and exercising in staff work with collaborators from other authorities responsible for rescue services and organisations in JRCC. *(RL 2016:11 R12)*

- Produce a basis for, and perform, training and exercising in searching in a mountainous environment for SAR crews maintaining preparedness in a mountainous environment in both daylight and darkness. *(RL 2016:11 R13)*

- Review procedures so as to minimise the time for preparations ahead of take-offs with SAR helicopters. *(RL 2016:11 R14)*

1. FACTUAL INFORMATION

1.1 History of the flight

1.1.1 Preconditions

The accident occurred in Sweden during a commercial cargo flight with mail from Oslo/Gardermoen Airport (ENGM) to Tromsø/Langnes Airport (ENTC).

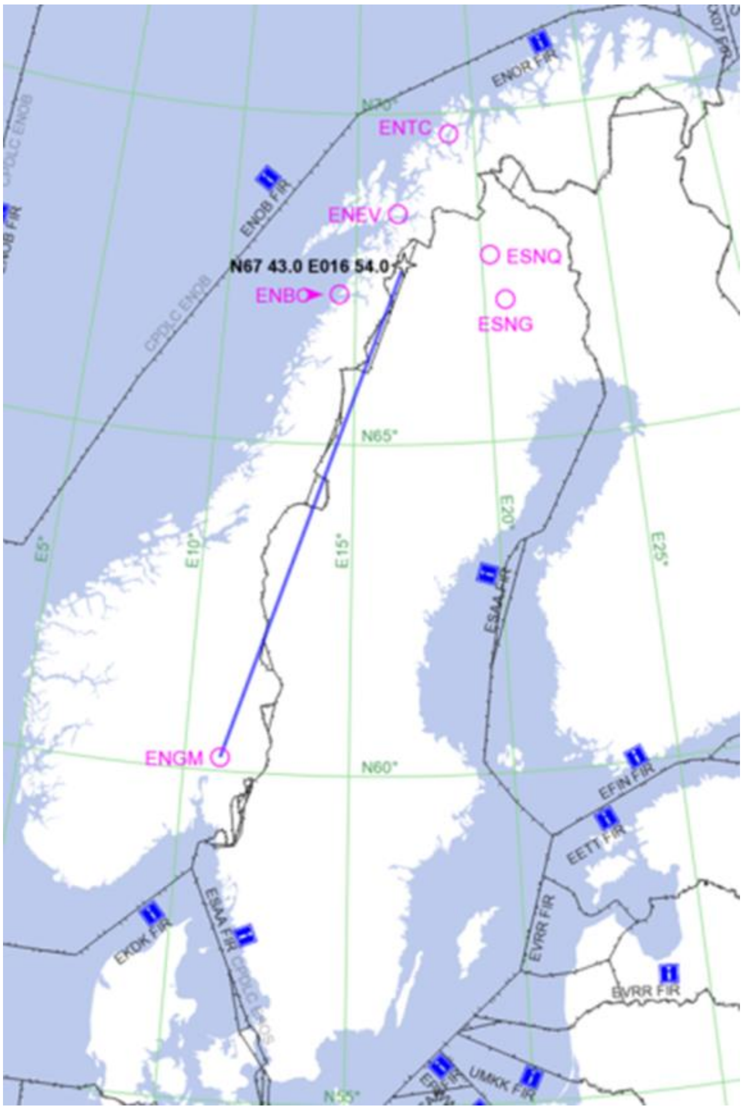

Figure 1. The flight route.

The pilot in command and the co-pilot had flown the sectors ENTC-ENEV and ENEV-ENGM earlier in the evening with the same aircraft. The crew's flight duty started at 18:10 hrs.

The aircraft was assigned the call sign SWN294 (Air Sweden 294). The flight was conducted under the ATS[8] flight plan as an IFR[9] flight. The requested altitude enroute was flight level 330 (FL330). The

[8] ATS – Air Traffic Service.
[9] IFR – Instrument Flight Rules.

flight planned route to ENTC was planned via waypoints and airways called NUVSA, T311, EGAGO, N150, MAVIP, T65, GILEN, P600 and LURAP. The route went more or less the shortest way to LURAP.

The planned take-off time was 23:00 hrs local time with a planned flight time of one hour and 43 minutes. The fuel endurance was two hours and 46 minutes.

SHK has received the flight planning documentation from the operator. The documentation consisted of weather information, NOTAM[10], operational flight plan and performance data.

According to the significant weather charts for the weather enroute (SWC), there was no significant weather which meant that there was no forecasted risk of icing, turbulence, precipitation or lee waves.

NOTAM did not indicate any information that prevented or modified the planned flight. The design and content of the operational flight plan was in accordance with applicable regulations.

1.1.2 Pre-flight preparations

The information in the following sections is based on information from voice and data recorders (CVR and DFDR), recordings from ATS, recordings from surveillance cameras at Oslo/Gardermoen Airport and interviews.

The cargo load was routinely anchored in sections. Each section was surrounded by vertical nets that are designed to withstand a longitudinal load of 9G.

The aeroplane was refuelled with 2 103 litres of the type Jet A-1.

A copy of the load sheet signed by the pilot in command indicated that the aeroplane's mass and balance were within allowable limits.

At 22:24 hrs the flight crew agreed that the pilot in command would be PF[11] and the co-pilot PM[12] on the actual sector. Three minutes later the ATIS[13] broadcast for Oslo/Gardermoen Airport could be heard. The information stated that runway 01 left was in use, the wind 020 degrees and five knots, visibility more than 10 km in light snow, temperature -13°C and dew point -15°C. The reported barometric pressure (QNH) was 1 007 hPa.

The pilot in command requested a clearance at 22:30 hrs. ATC cleared the flight to Tromsø, runway 01 left (for take-off), NUFSA 4A departure and transponder code 4511, which was acknowledged with a request for de-ice.

[10] NOTAM – Notice to Airmen.
[11] PF – Pilot Flying.
[12] PM – Pilot Monitoring.
[13] ATIS - Automatic Terminal Information Service.

At 22:47 the co-pilot started to read the “Before Start” checklist. All items in the first part of the checklist were read and acknowledged by the pilot in command.

At 22:48 the co-pilot contacted ATC and requested engine start for which clearance was given. The second part of the checklist was read and thereafter both engines were started. At 22.52 the co-pilot read all the items in the “After start” checklist which were acknowledged by the pilot in command. Thereafter the pilot in command requested taxi clearance from the tower and taxiing to the de-ice ramp was initiated.

The de-icing started at 23:01 hrs. A two-step de-icing was performed which meant that both de-icing fluid of Type I (removal of ice, frost and snow) and of Type II (to avoid refreezing) were used. The aeroplane’s wings, horizontal and vertical stabilizer were treated. During the de-icing procedure the co-pilot read all the items of the “De-icing” checklist which were acknowledged by the pilot in command. In accordance with the procedure a flight controls check of ailerons, spoilerons, rudder and elevator was performed. DFDR-data and information from one of the CCTV cameras confirmed that the flight controls check was satisfactory.

At 23:04 hrs taxi clearance was requested and received. Taxiing was started to the holding point for runway 01 left. The pilot in command conducted a take-off and departure briefing. All the items on the “Taxi” and “Before Take-off” checklist were read by the co-pilot and acknowledged by the pilot in command. An engine run-up was performed immediately before take-off. According to the aeroplane’s operating manual, the purpose of the run-up is to clear the engines from residual de-icing fluids.

1.1.3 The take-off, departure, climb and cruise phase

The take-off took place at 23:09 hrs in a northerly direction from runway 01 left. The take-off, departure and climb to the cleared flight level, FL 330, were performed according to normal procedures. The autopilot was engaged during the climb at approximately FL 180. At 23:37 the aeroplane was established in level flight at FL 330.

The aeroplane crossed the border and entered Swedish airspace approximately in a position abeam Bodø but was still in the airspace called Area Silver, which was controlled by Norwegian ATC. The flight crew had received a clearance direct to the waypoint VAMEN and also information to expect an approach to runway 01 at Tromsø with circling[14].

Thereafter, the pilot in command asked the co-pilot if he was ready for a briefing, which he acknowledged. Nothing has emerged from the recordings indicating that the manoeuvring of the aeroplane was

[14] Circling – An extension of an instrument approach procedure which provides for visual circling of the aerodrome prior to landing.

handed over to the co-pilot before briefing. The briefing was conducted during almost one minute and was continuously acknowledged by the co-pilot. The briefing covered all the items of the approach in question.

Until the start of the event, nothing has emerged that indicates deviations from normal procedures or normal setting in the cockpit regarding controls or switches.

The CVR recording indicates that all conversations between the pilots were conducted in English. There were conversations both of operational and of private nature. All conversations were conducted without any evidence of misunderstandings between the pilots.

The aeroplane was in level flight at FL 330 (about 10 600 metres) on the magnetic heading of 014 degrees, with an indicated airspeed (IAS) of 275 knots and a groundspeed of 422 knots. The autopilot and the yaw damper were engaged. All recorded DFDR parameters were stable with normal values from the point in time when the aeroplane first levelled out at the cruise altitude.

1.1.4 The occurrence and the accident

*The time designations during the occurrence in the text below are given in seconds together with the letter **t**, meaning that the start of the occurrence is **t0**, corresponding to 00:19:20 hrs.*

DFDR-data indicates an increase of the pitch angle at **t0**, during the approach briefing. From a constant value of about 1 degree the angle increased to 1.7 degrees. Thereafter the rate of increase of the pitch angle was approximately 6 degrees per second during the following six seconds.

The recorded pitch angle emanated from the aeroplane's IRS[15] 1, which with normal settings in the cockpit, also fed PFD 1, the left pilot's primary flight display, with the same information.

At **t2** the pilot in command who was seated in the left seat, exclaimed a strong expression *"What (!)"*. According to DFDR-data the recorded pitch angle had now increased to approximately 15 degrees but the recorded altitude, speed and angle of attack[16] remained unchanged (the angle of attack is not displayed to the crew).

Immediately thereafter the aural warning for the autopilot disconnect (referred to as Cavalry Charge) was activated. The disconnection is confirmed by DFDR-data. According to the aeroplane's manufacturer, the autopilot was most likely automatically disconnected due to differences in the pitch servo commands. The aural warning remained active for the next 18 seconds.

15 IRS – Inertial Reference System.
16 Angle of Attack – Angle between the oncoming relative airflow and the mean wing chord.

At **t3** an aural caution named “Single Chime[17]” was recorded.

Approximately at the same time, DFDR-data indicate that both left and right elevators moved to a position that causes the aeroplane to pitch down. The angle of attack recorded from vanes on the aeroplane’s left and right side changed to negative values. DFDR-data also indicate that the moveable horizontal stabilizer trim was manually activated from the left control wheel trim switch during 19 seconds. During this period, the right control wheel trim switch was also activated during 3 seconds. The left control wheel switch has priority over the right switch. The trim position initially increased at a slow rate towards nose down, from the initial recorded value of -0.9 degrees (aeroplane nose up).

At **t5** the recorded pitch angle exceeded 30 degrees which meant that, by design, red chevrons pointing down were displayed on PFD 1 and any displayed miscompare indications are removed (a function called declutter[18]). The speed of the stabilizer trim change increased from that time and reached 1.7 (aeroplane nose down) at **t12**. The aeroplane started to descend with vertical acceleration values momentarily reaching negative values of -1G. At the same time the CVR recorded irregular sounds for a period of about five seconds.

At **t9**, after a few seconds with negative G-load, the aeroplane’s warning system was activated with a Triple Chime. Immediately thereafter the CVR recorded a strong expression from both the co-pilot and the pilot in command followed by an audio signal (synthetic voice) *“Engine Oil”* for low oil pressure in the engines. According to the engine manufacturer, the warning was due to the negative G-load.

At **t11** an audio signal for the stabilizer trim movement (Stab trim clacker) was activated, which meant the stabilizer position movement had been sensed at a high rate for more than three seconds. In this case the stabilizer movement was due to manual trim switch command. Immediately thereafter Triple Chime was activated again and interrupted by two audio warnings *“bank angle”* which meant that the aeroplane’s roll angle reached at least 40 degrees. At the first *“bank angle”* warning the co-pilot said *“Come up”*. At the second *“bank angle”* warning the co-pilot said *”Turn right”* and the pilot in command simultaneously said *”Come on, help me, help me, help me”*.

At **t17**, the maximum operating speed (V_{MO}) of 315 knots and the maximum operating Mach number (M_{MO}) of 0.85 were exceeded almost simultaneously. The audio signal for overspeed (Overspeed clacker) was activated and at the same time the vertical acceleration returned to positive values. The warning remained activated until **t72**. The pilot in command asked for help again which was answered by the co-pilot by saying *“Yes, I am trying”*. When the vertical accelera-

[17] Chime – Audio signal used for different cautions and warnings.
[18] Declutter – Refers to the removal of information that is not pertinent.

tion turned to positive values the CVR recorded irregular sounds again during a period of more than 2 seconds.

At **t20** the audio signal from the autopilot disconnect warning ceased and simultaneously a *"Bank angle"* warning was heard again. The co-pilot now said "*Turn left"* three times, followed by *"No"* and simultaneously two Single Chime audio cautions sounded.

At **t23** the recorded indicated airspeed reached 364 knots, corresponding to Mach 0.91, which meant that M_D[19] was exceeded.

At **t30** the co-pilot transmitted a distress call *"Mayday, Mayday, Mayday, Air Sweden 294"* which was acknowledged by ATC. Then the co-pilot transmitted another emergency call and at the same time two Single chime cautions sounded. The co-pilot then stated an intent to call ATC back, "*We call you back, Mayday, Mayday"*.

By now the recorded indicated airspeed had increased to 400 knots, corresponding to the aeroplane's maximum design speed (V_D[20]), and the recorded altitude was about 24 000 feet. The horizontal stabilizer trim was activated once again from the left control wheel switch and was reduced to 0.3 degrees aeroplane nose down. Immediately thereafter the left control wheel pitch trim disconnect switch was activated. The pilot in command said *"Mach trim"*[21] which was answered by the co-pilot with *"Trim, trim a lot"*.

At **t40** an ATC call to the flight was heard but was not acknowledged by the flight crew. Another Single chime was heard; thereafter, the engine thrust was reduced to idle. Audio warnings *"Bank angle"* were heard continuously by now until the end of the event.

During the further course of the event, the last recorded DFDR value for indicated airspeed shows a continuous increase to 508 knots. The recorded vertical acceleration indicates positive values peaking at approximately +3G. DFDR data further indicate that the aeroplane's ailerons and spoilerons were mainly deflected to the left during the event. The flight crew's dialogue was by now mainly about different opinions about turning directions. The crew also expressed the need to climb.

At **t57** another Single Chime was recorded. At about the same time the controller transmitted a call according to ATC recordings.

The aeroplane collided with the ground in an inverted position at **t80,** one minute and twenty seconds after the start of the event.

[19] M_D – Design Diving Speed expressed in Mach number.
[20] V_D – Design Diving Speed.
[21] Mach trim – A caution referring to the automatic trim system that compensates for the aeroplane's tendency to pitch down with increasing Mach number.

Radar recordings and the position of the accident site indicated that the aeroplane's trajectory changed by 75 degrees to the right during the event.

The accident occurred during darkness at 00:20:40 hrs, at position 6743N 01654E, 722 metres above mean sea level.

1.2 Injuries to persons

	Crew members	Passengers	Total on-board	Others
Fatal	2	-	2	-
Serious	-	-	0	-
Minor	-	-	0	Not applicable
None	-	-	0	Not applicable
Total	2	0	2	-

1.3 Damage to aircraft

Destroyed.

1.4 Other damage

1.4.1 Environmental impact

Ground damage and spillage from fuel and oil.

1.5 Personnel information

1.5.1 The pilot in command

The pilot in command was 42 years old and had a valid ATPL(A) license with flight operational and medical eligibility. At the time the commander was PF[22].

Flying hours				
Latest	24 hours	7 days	90 days	Total
All types	3	15	130	3 365
Actual type	3	15	130	2 208

The total flight hours on actual type consist of 639 hours on CRJ900 and 1 569 hours on CRJ200.

Number of landings actual type previous 90 days: 93.
Skill test on type was conducted on 23 August 2008.
ATPL was obtained on 17 March 2014. The skill test was conducted on type.
Latest PC[23] was conducted on 23 February 2015 on type.

The pilot in command's basic flight training was performed at the Airman aeronautical school in Malaga and in Madrid, Spain. The

[22] PF - Pilot Flying.
[23] PC - Proficiency Check.

training was conducted in modules and included PPL[24], CPL[25], ATPL theory and MCC[26].

During the basic flight education, the pilot in command was subjected to a psychological assessment and was subsequently approved.

The basic training did not include aerobatic flight.

The pilot in command had earlier experience on CRJ900 with another operator.

The pilot in command successfully attended theoretical and practical courses in SOP[27] and CRM[28] with the current operator.

During the type rating, practical simulator training was conducted regarding mandatory manoeuvers and items, and amongst other procedures, the abnormal procedure "EFIS COMP MON[29]".

1.5.2 The co-pilot

The co-pilot was 33 years old and had a valid CPL(A) license with flight operational and medical eligibility. At the time the co-pilot was PM[30].

Flying hours				
Latest	24 hours	7 days	90 days	Total
All types	3	13	130	3 232
Actual type	3	13	130	1 064

Total hours on actual type are acquired on CRJ200.

Number of landings actual type previous 90 days: 94.
Type rating concluded on the type on 12 September 2013.
Latest PC was conducted on 15 September 2015 on type.

The co-pilot's basic flight training was conducted at the EPAG flight school in France. The training was conducted as ab initio training[31] and included training to CPL, ATPL theory and MCC.

The basic training did not include aerobatic flight.

The co-pilot started his commercial pilot career with the operator on the type BAE/ATP/Jetstream 61.

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[24] PPL –Private Pilot License.
[25] CPL – Commercial Pilot License.
[26] MCC – Multi Crew Cooperation.
[27] SOP – Standard Operating Procedures.
[28] CRM – Crew Resource Management.
[29] EFIS COMP MON – EFIS Comparator Monitoring – Caution for abnormal differences between the PFD-units.
[30] PM (Pilot Monitoring).
[31] Ab initio training – Training from scratch to Commercial Pilot.

During the type rating, practical simulator training was conducted regarding mandatory manoeuvers and items, and amongst other precedures, the abnormal procedure “EFIS COMP MON”.

1.5.3 Duty schedule of the crew

The pilot in command was working on his fifth shift (out of one evening and four evening/night shifts) when the accident occurred. During the first four shifts the flights ended at 21:50, 02:02, 00:33 and 01:45 hrs. The co-pilot was working on his fourth evening/night shift. During the first three shifts the flights ended at 02:02, 00:33 and 00:42 hrs.

The accumulated weekly duty time for the pilots was 32.5 hours which did not exceed flight time limitations.

The accident occurred on the third and last sector of the shift.

1.6 Aircraft information

The aircraft model CL-600-2B19 is a twin-engine regional jet aeroplane with the marketing name CRJ 200PF (Canadair Regional Jet 200 Package Freighter). The aircraft is intended for the transport of cargo on short and medium range. The aircraft has a length of 26.77 meters, a wingspan of 21.21 meters and is pressurized.

Figure 2. The aircraft SE-DUX (Photo: West Atlantic Sweden AB).

The aircraft features two turbofan engines manufactured by General Electric. The aircraft is mainly made of aluminium and is divided into cockpit and cargo sections.

1.6.1 The aeroplane

TC[32]-holder	Bombardier Inc.
Model	CL-600-2B19
Serial number	7010
Year of manufacture	1993
Gross mass, kg	Max authorized take-off/landing mass 23 995/21 200, current 19 912
Centre of gravity	Within allowable limits, 16 % MAC[33] (Min 9 Max 32).
Total flying time, hours	38 601
Number of cycles	31 036
Type of fuel uplifted before the occurrence	Jet A1

Engines	CF34-3B1	
TC-holder	General Electric Company	
Type	Turbofan	
Number of engines	2	
Engine	No 1	No 2
Serial number	873011	807033C
Total operating time, hours	24 517	36 543
Operating time since last inspection, hours	197	197

Deferred remarks	None

The aircraft had a Certificate of Airworthiness and a valid ARC.

1.6.2 Description of parts or systems related to the occurrence

The aeroplane's six degrees of freedom

An aeroplane has six degrees of freedom consisting of three rotational and three translational movements (figure 3).

The rotational movements take place around the aeroplane's three axes, the lateral axis, the longitudinal axis and the vertical axis.

The lateral axis passes basically through the plane from wingtip to wingtip. A movement around the lateral axis is referred to as pitch and its plane is called the pitch plane. An increased pitch angle means that the nose of the aeroplane moves up as seen from the pilot's position while a decrease means that the nose moves down.

The longitudinal axis passes through the plane from nose to tail. A movement around the longitudinal axis is referred to as roll and its plane is called the roll plane. A change in the roll angle means that the

[32] TC - Type Certificate.
[33] MAC – Mean Aerodynamic Chord.

aeroplane will bank to the left or to the right as seen from the pilot's position.

The vertical axis is perpendicular to the wings with its origin at the centre of gravity and directed towards the bottom of the aircraft. A movement around the vertical axis is referred to as yaw and its plane is called the yaw plane. A change in the yaw angle means that the nose of the aeroplane moves to the left or to the right as seen from the pilot's position.

The translational movements take place along the aeroplane's three axes.

A change of velocity along the longitudinal axis causes changes to the horizontal acceleration (Gx). A change of velocity along the vertical axis causes changes to the vertical acceleration (Gz). A change of velocity along the lateral axis causes a change in the lateral acceleration (Gy).

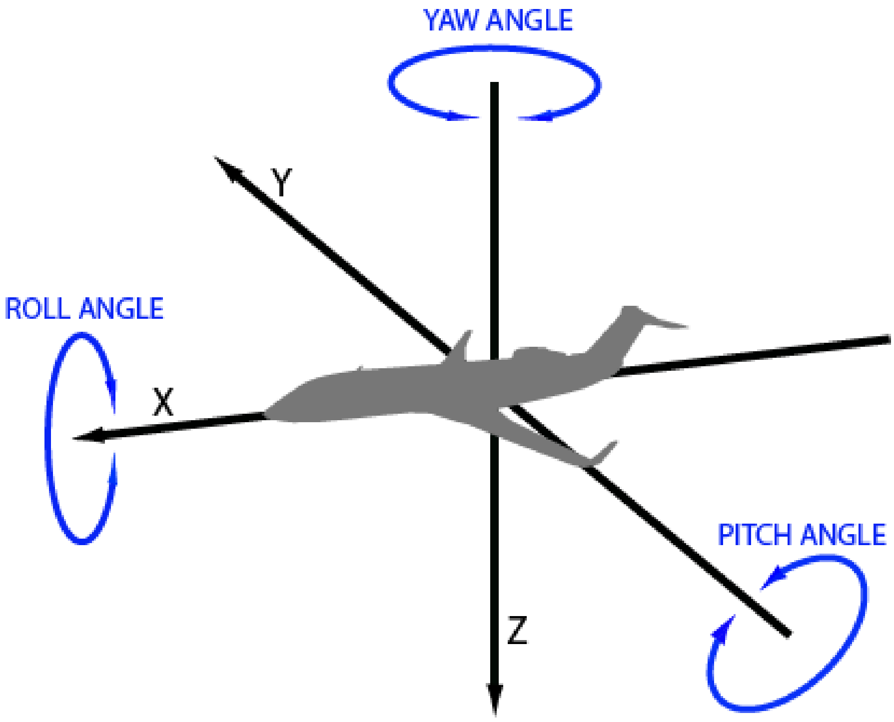

Figure 3. The aeroplane's six degrees of freedom.

Flight Controls

The aeroplane's flight controls are of conventional type operated by control wheels, control columns and rudder pedals. Control surfaces are actuated either hydraulically or electrically. The flight control systems include major control surfaces, components and subsystems that control the aircraft during flight. The flight controls are divided into primary and secondary controls.

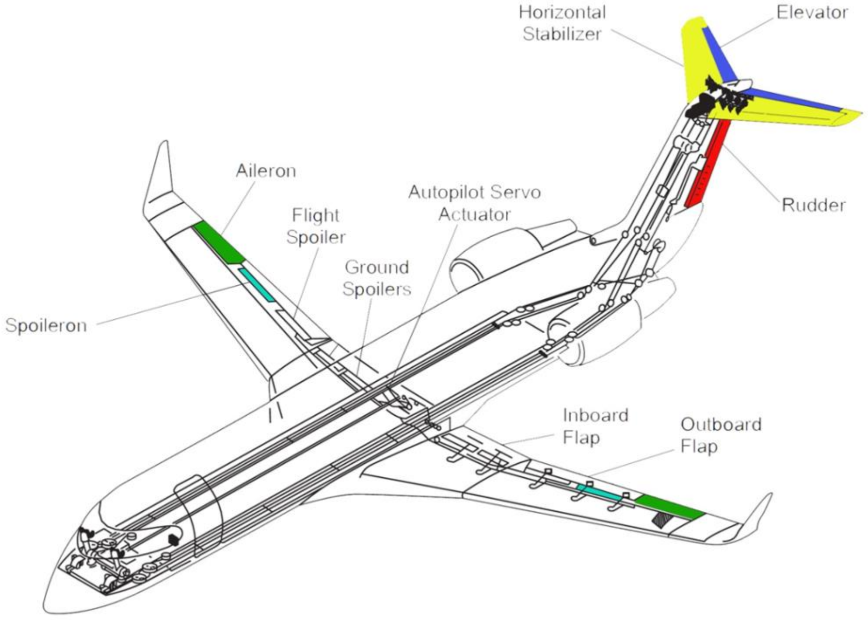

Figure 4. Flight control surfaces.

The primary flight controls include:

- Elevators
- Ailerons
- Spoilerons
- Rudder

The elevators, ailerons and rudder are controlled by cables, pulleys, push/pull rods and levers that transmit control column and rudder pedal inputs to hydraulic power control units.

The aeroplane is equipped with three independent hydraulic systems. Each aileron and spoileron is powered by two hydraulic systems. The rudder and elevators are powered from all three hydraulic systems.

Spoilerons are used to augment roll effectiveness and activated when large aileron inputs are made.

To allow the pilots to feel aerodynamic loads on the control surfaces there is an artificial feel system that generates control resistance.

In the event of a blockage in one of the control systems the left and right elevator and aileron control systems can be disconnected respectively.

Flight control status and surfaces' positions are displayed on the EICAS[34] primary page, status page and flight controls synoptic page.

A protection system warns for and prevents stall[35].

[34] EICAS – Engine Indication and Crew Alerting System.
[35] Stall - An aerodynamic loss of lift caused by exceeding the critical angle of attack.

The secondary flight controls include:

- Flaps
- Flight spoilers
- Ground spoilers
- Aileron and rudder trim
- Horizontal stabilizer trim

The purpose of flight spoilers is to reduce speed in flight. Ground and flight spoilers are used on the ground to reduce the stopping distance of the aircraft. These systems are electrically controlled and hydraulically actuated.

The horizontal stabilizer supplies pitch trim to the aircraft and operate in one of four modes. These modes are in operational priority: manual trim, auto trim (during flap 0-20 degrees movement), Mach trim and autopilot trim. The range of movement of the horizontal stabilizer is between +2 degrees (aeroplane nose down) and -13 degrees (aeroplane nose up).

The inputs during manual trim mode are the pilot and copilot trim switches on the left and right control wheel. When manual trim is applied the rate of movement of the horizontal stabilizer is 0.5 degrees per second. An Aural Warning (Stab trim clacker) is provided when the stabilizer position movement is sensed at a high rate for more than 3 seconds.

The pitch trim disconnect switch on pilot and co-pilot control wheel is used to disconnect the system.

Figure 5. Switches on left control wheel. (Same set of switches are also located on the outboard handle of the right control wheel).

EFIS

The Electronic Flight Instrument System (EFIS) provides the flight crew with flight and navigation information. All basic flight information is presented to the flight crew on the EFIS displays. Each pilot instrument panel contains a Primary Flight Display (PFD) and a Multi-Functional Display (MFD).

Each PFD displays, inter alia, attitude, altitude, airspeed, heading, flight director commands and status, autopilot status, flight modes annunciations and navigation information.

Each MFD displays navigation information. The MFD also gives a reversion alternative for the PFD and EICAS.

A Source Selector panel situated on the centre pedestal is used to select alternate sources of information for critical systems allowing information to be provided from the remaining operational source. For example if the ATTD HDG[36] switch is set from NORM to 2, both PFDs will receive information from IRU 2.

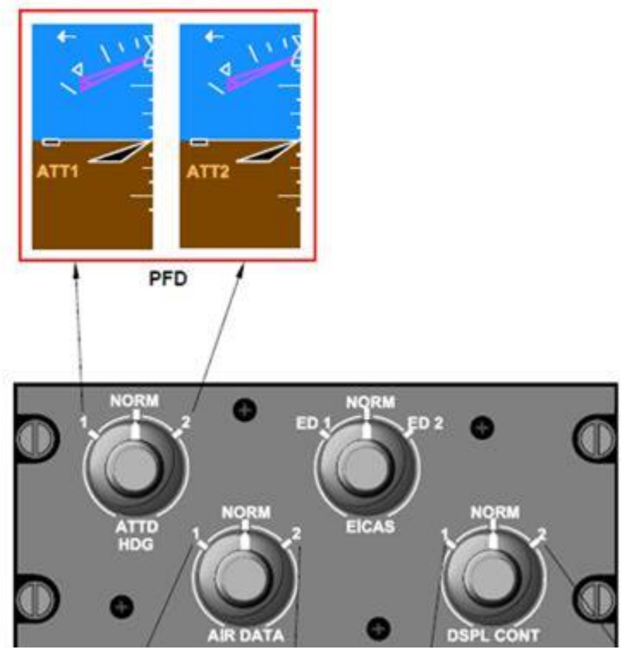

Figure 6. Source Selector Panel.

Normally, PFD 1, in front of the left pilot, displays information from IRU 1 and PFD 2, in front of the right pilot, displays information from IRU 2.

The information displayed on each PFD is monitored by a comparator system.

Primary flight displays together with the standby instruments provide redundancy in three independent flight instruments systems.

[36] ATTD HDG – Attitude Heading.

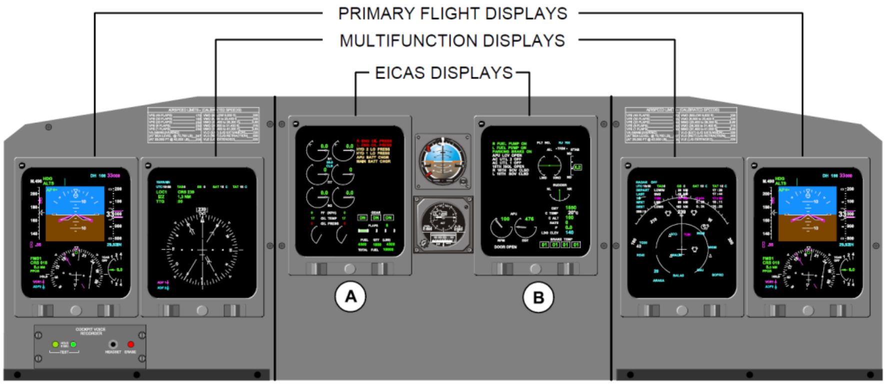

Figure 7. PFD, MFD and EICAS displays.

Standby instruments

Standby instruments provide, inter alia, attitude, altitude and airspeed information to the flight crew. An independent standby compass provides magnetic heading.

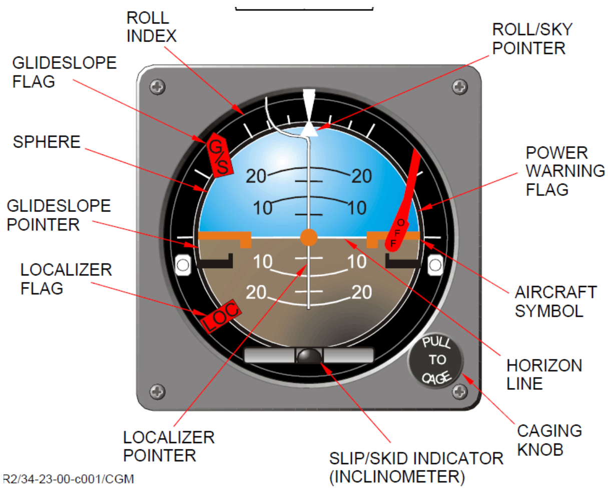

Figure 8. Standby attitude instrument.

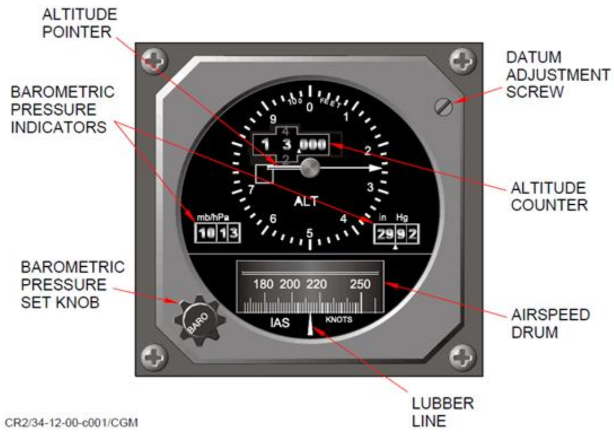

Figure 9. Standby altimeter and airspeed indicator.

Comparator functions

A comparison of displayed data is performed by each PFD to ensure that the same data is shown on both PFDs. Each PFD performs its own monitoring and operates its own miscompare indicators. Comparison of roll, pitch, heading, altitude and airspeed information is performed continuously.

When a miscompare condition is detected (out of limits), the miscompare indicator on both PFDs will flash amber for five seconds then come on steady, as long as the miscompare exists. An EFIS COMP MON caution message is displayed on the EICAS primary page together with Master Caution annunciation and aural alert (Single Chime).

For pitch, roll and heading miscompare conditions the applicable miscompare indicators PIT, ROL and HDG are displayed in a yellow box on each PFD (figure 10).

Comparator Caution trips when there is more than 4 degrees difference in Pitch or Roll information between PFD 1 and PFD 2.

The miscompare indicator on the PFDs has a 0.7 second delay threshold. There is a further delay of 1 second plus transport delay inside the Data Concentrator Unit before the EFIS COMP MON caution message is displayed on EICAS.

Figure 10. Comparator caution indications on PFD.

Unusual Attitude

When the indicated pitch angle exceeds + 30 degrees, is less than – 20 degrees or when the roll angle exceeds 65 degrees a function called declutter is activated and all secondary information is removed. This means that e.g. PIT and ROL cautions in the attitude display are removed.

Red double arrows (chevrons) pointing up or down in relation to the artificial horizon line are displayed on the attitude scale pointing in the direction of recovery (figure 11). Unusual attitude indicators are removed when pitch angle or roll angle returns within the normal operating attitude.

Figure 11. Unusual attitude with chevrons.

PFD failure flags

If there is a failure in the attitude information to a PFD there is a flag warning on the PFD with the failed attitude source with the letters ATT in a red box and attitude information is removed (figure 12).

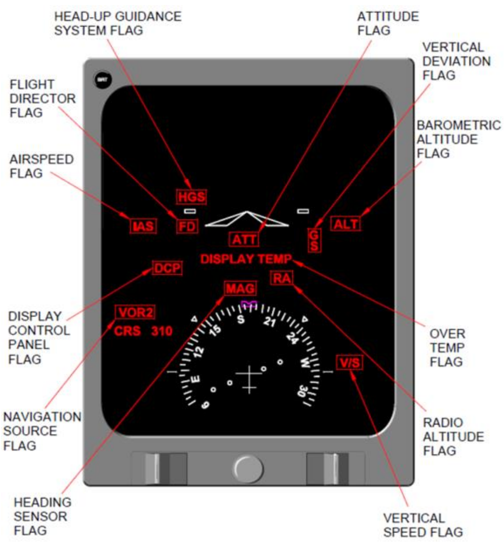

Figure 12. Failure flags on PFD.

EICAS

Data from the aeroplane systems is received and processed by two Data Concentrator Units (DCU) which provide information to the EICAS displays.

The DCUs also provide interface with the Flight Data Recorder System (FDR) and Maintenance Diagnostic Computer (MDC) via the Integrated Avionics Processor System (IAPS).

EICAS provides the crew with alerting system messages that are posted on the EICAS displays in the form of warning, caution, advisory and status messages.

Master Warning and Master Caution lights on the glare shield draw crew attention to newly posted warning and caution messages on EICAS. Audio signals are generated within DCUs and are heard through the cockpit speakers.

A Master caution generates a Single Chime while a Master Warning generates a Triple Chime. Each Master Warning and Master Caution will generate a corresponding text message on the EICAS primary display.

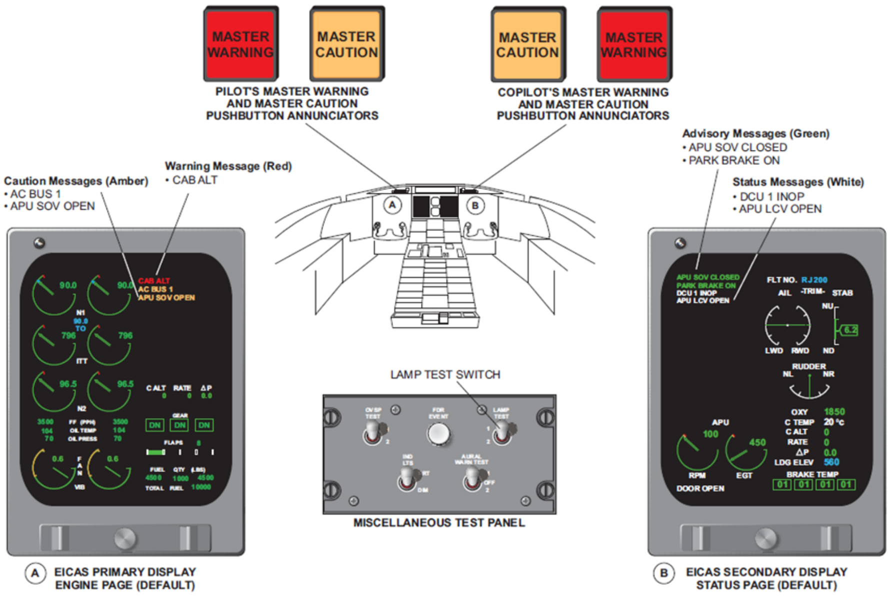

Figure 13. EICAS with Master Warning and Master Caution lights.

The aural warnings generated by EICAS include inter alia:

- Cavalry charge (Autopilot disconnect)
- Engine oil (Synthetic voice) (Low engine oil pressure)
- Stab trim clacker (Audio signal for stabilizer movement)
- Overspeed clacker (Audio signal for overspeed)

EGPWS

The enhanced ground proximity warning system (EGPWS) supplies visual and aural warnings and alerts related to, inter alia, the aircraft ground (terrain) clearance, sink rate, and terrain/obstacle awareness. The system also supplies aural indications of specified radio altitudes (RA) and bank angle limits.

For all altitudes above 150 feet the thresholds for bank angle callout are at 40, 48 and 56 degrees roll angle. For this aeroplane model, EGPWS uses attitude information from IRU 2 as default. If IRU 2 fails the EGPWS uses attitude information from IRU 1.

IRS (Inertial Reference System)

The Inertial Reference System includes two IRUs (Inertial Reference Unit), IRU 1 and IRU 2, and one MSU (Mode Selector Unit).

The system generates the following information:

- Attitude (pitch roll, and yaw)
- Angular rates (pitch roll, and yaw)
- Linear accelerations (vertical, longitudinal and horizontal)
- True heading
- Magnetic heading (synthetic)
- Present position
- Track (true and magnetic)

IRU

IRU transmits to its receivers through data-busses, where the outputs are sent as “words” consisting of bits, or the binary digits 1 or 0. Each word contains 32 bits where specific bits describe various data (e.g. pitch or roll angle), the actual value and a validation of the word. The validation is called SSM[37] and is the result of the unit’s continuous self-tests. The purpose of this is to enable the receivers to trust the reliability of the output.

Each IRU consists of three ring laser gyros (RLG), a three axis accelerometer and the computing section. A RLG senses angular changes around its axis by measuring frequency differences between the two counter rotating laser beams. The accelerometers sense acceleration along the same axis, acceleration is integrated to velocity and velocity is integrated to distance. Hence the IRU calculates the three dimensional trajectory and aeroplane’s angles in pitch, roll and yaw axis.

Operation of the unit starts with power up test and detection of actual latitude which is compared to the manually entered position. When present position and aircraft angles are determined the unit is ready for operation.

[37] SSM – Sign Status Matrix.

DFDR

The DFDR is a solid state data recording unit that monitors real time flight data and stores it in a non-volatile memory, meaning a memory unit that keeps stored information after power interruption. The DFDR receives the data through a data bus from the data acquisition function of DCU 1 with DCU 2 as backup.

A triaxial accelerometer installed in the left landing gear wheel-well provides acceleration information on three axes to the flight data recorder.

During normal conditions the DFDR is provided with attitude information from IRU 1 via the DCU 1.

AFCS

The Automatic Flight Control System (AFCS) provides integration of the autopilot and flight director systems. The system consists of two interlinked Flight Control Computers (FCC).

The FCCs receive data from the following systems:

- Flight control panel
- Air data systems
- Navigation systems
- Inertial Reference Systems
- Radio Altimeters
- Surface position sensors

The flight director provides visual guidance using a command bar on the attitude director indicator part of the primary flight displays.

The autopilot can be disengaged manually or automatically. A disconnection causes a warning signal called “Cavalry Charge”. The warning will be automatically silenced after 3 or 4 iterations lasting a total of approximately 1.5 seconds at manual disconnection or earlier if the disconnect pushbutton is pressed a second time.

Automatic disconnection will activate the warning continuously until the autopilot is reengaged or the disconnect pushbutton is pressed.

According to the manufacturer, the autopilot was disconnected automatically, probably due to differences between commands to the pitch servos.

Lights

Cockpit lighting consists of panel, integral and miscellaneous lighting. The miscellaneous lighting consists of different chart reading lights, dome light and floodlights.

1.7 Meteorological information

According to SMHI's analysis:

At FL330: wind northwest 30 knots, visibility >10 kilometres, no clouds, temperature -60 to -63°C.

At the accident site: wind light and variable, visibility >10 kilometres, no clouds, temperature -20 to -25°C, dew point -30°C, QNH 1010 hPa.

The accident occurred during darkness without any moonlight.

1.8 Aids to navigation

Several VOR stations and NDB beacons were available within the range of the aeroplane.

1.9 Communications

During the event, the crew was in contact with Norway Control. The distress calls that were transmitted during the event were acknowledged by ATC.

1.10 Aerodrome information

Not applicable.

1.11 Flight recorders

The aeroplane was equipped with a flight data recorder (DFDR, Digital Flight Data Recorder) and a CVR (Cockpit Voice Recorder). The units were heavily demolished and have been recovered. The memory unit had separated from the CVR chassis. Both units including the CVR memory unit were transported by SHK’s staff to the French accident investigation authority, BEA, for readout.

Figure 14. DFDR-unit.

Figure 15. CVR chassis.

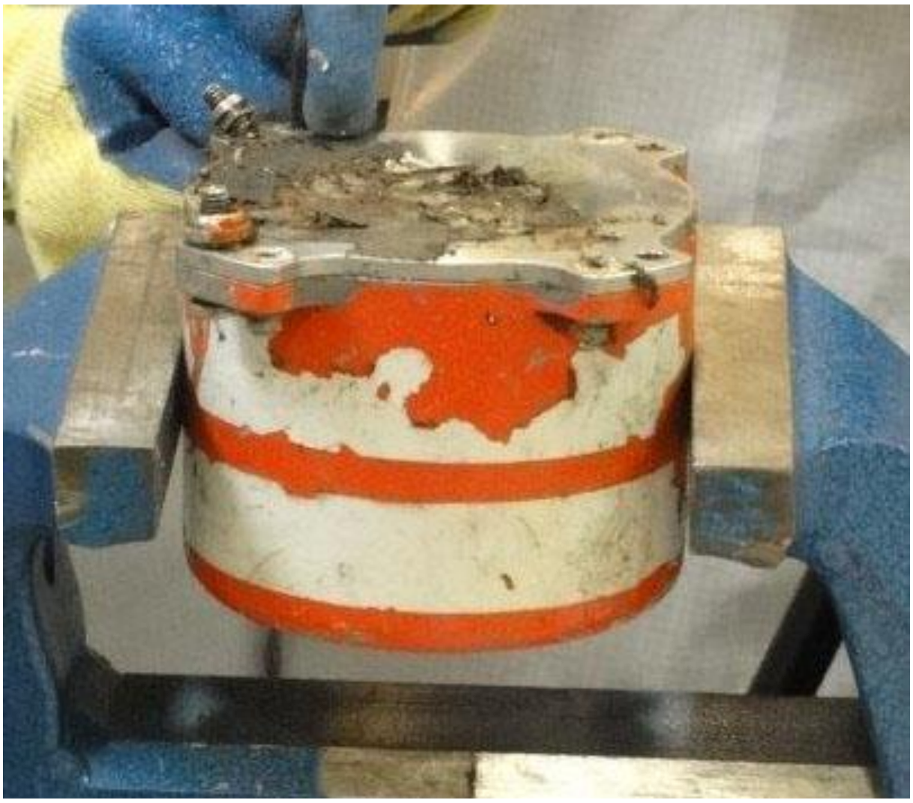

Figure 16. CVR memory module.

1.11.1 Digital Flight Data Recorder (DFDR)

The DFDR of the model F1000 from L-3 Communications Aviation Recorders, Inc. had the part number S800-2000-00 and the serial number 01038.

The CSMU (Crash-Survivable Memory Unit) was opened to extract the memory board. The board was connected to a reference frame to be able to download data. Binary data was downloaded and converted to engineering units via the aircraft's parameter list.

The list contains 137 parameters of which 52 were continuous and 85 were discrete. Continuous parameters contain different values within certain limits while discrete parameters contains only two values e.g. on or off.

All parameters could be read out. Among the parameters useful for the investigation, the validation of the parameters showed that four of the parameters were not compatible with the aircraft's actual movement. The concerned parameters were pitch angle, roll angle, magnetic heading and ground speed. Those parameters emanate from the aeroplane's IRU 1 unit and are described in section 1.16.7.

Selected parameters are presented in appendix 1.

1.11.2 Cockpit Voice Recorder (CVR)

The CVR of the model FA2100 from L-3 Communications Aviation Recorders, Inc. USA had the part number 2100-1020-00 and the serial number 570736.

The CSMU (Crash-Survivable Memory Unit) was opened to extract the memory boards. The memory boards were connected to a reference frame in order to download data from four channels.

The channels consist of one public address channel, two channels for left and right pilot position and one channel for cockpit area sound.

The four channels were downloaded successfully and resulted in four sound files of two hours and four minutes with high quality.

Information about the dialog between the pilots is included in section 1.1.

A CVR transcript for the last 85 seconds of the event is presented in appendix 2.

1.12 Accident site and aircraft wreckage

1.12.1 Accident site

The accident site is located in an almost flat part of a valley in mountainous terrain. In connection with the accident, a crater was formed. The crater was approximately 6 meters deep and 20 meters in diameter. The bottom of the crater was filled with about 1.5 cubic meters of fluid consisting of aviation fuel and water.

Figure 17. Accident site with 10 meter distance circles. CVR was found at the red cross closest to the center, DFDR at the second cross (Photo: Swedish Police).

1.12.2 Aircraft wreckage

The aircraft was destroyed. Debris was found up to a distance of about 150 meters from the crater. Most parts were found in the crater and to the northeast of it (figure 17 above). Mapping of the debris was made according to the polar method, which means that one starts from the centre of the accident site and specify distance and direction.

The distribution of the debris shows that the aeroplane hit the ground approximately in an easterly direction. The main part of the right wing was found in the northern part of the crater, while the main part of the left wing was found in the southern part, which indicates that the aircraft collided with the ground in an inverted position.

Wreckage recovery

During the first visit at the accident site, about 3.5 tons of debris, equivalent to more than 25 percent of the basic empty mass of the aeroplane and about 1 ton of cargo was recovered for further investigation (figure 18).

Figure 18. First visit at the accident site.

At the second visit during summer (figure 19) approximately 9.5 ton of debris from the aircraft and the cargo was recovered and examined.

Figure 19. Second visit at the accident site.

Examination of parts from the wreckage

The examination of the wreckage parts showed that primary and secondary flight controls were at the accident site as well as winglets, parts of the nose and tail section.

Except for the crash protected recorders, instruments and electronic components had such damage that there was no possibility to retrieve or read out any data from any NVM (Non Volatile Memory).

1.13 Medical and pathological information

Nothing has emerged indicating that the pilots' mental or physical state was impaired before the start of the event.

1.13.1 The biological circadian rhythm

The biological clock governs not only physiological activities such as body temperature and digestion, but also performance, wakefulness and frame of mind.

The biological clock is programmed for a lowest level of activity around 2 to 5 o'clock in the morning. It is a period of low activity, physiologically and functionally. Performance impairments may occur within a larger window from about 24 to 6 o'clock in the morning.

In the case in question, the incident occurred at 00:20 hrs in the morning.

1.13.2 The flight crew's sleep and rest periods

There is no information concerning the crew's sleep periods during the days preceding the accident.

During the three days preceding the accident the crew had had access to daily rest periods of at least 15 hours per day.

1.14 Fire

Approximately 1 ton of the mail cargo was examined by SHK with the assistance of an investigator and a fire expert from the Norwegian accident investigation authority, SHT.

There was no sign of fire or explosion.

1.15 Survival aspects and the rescue operation

The accident was not survivable.

1.15.1 General

Provisions on rescue services are found primarily in the Civil Protection Act (2003:778) and the Civil Protection Ordinance (2003:789), in the following referred to by use of their acronyms in Swedish, LSO and FSO respectively.

The term "rescue services" denotes the rescue operations for which central government or municipalities shall be responsible in the event of accidents or imminent danger of accidents, in order to prevent and limit injury to persons and damage to property and the environment. In order for an operation to be considered a rescue service it shall be justified on the basis of the following four criteria: the need for a rapid response, the importance of the interest threatened, costs for the operation and other circumstances.

Central government is responsible for mountain rescue services, air rescue services, sea rescue services, environmental rescue services at sea and rescue services in case of the emission of radioactive substances, as well as for searching for missing persons in certain cases. In other cases, the authorities of the municipality concerned are responsible for the rescue services. There can be parallel rescue operations at the same time.

In every rescue operation there shall be a rescue commander with the necessary competence. In municipal rescue services, the rescue commander is the head of rescue services or the person appointed by him or her. In central government rescue services, the rescue commander is appointed by the responsible authority.

Pursuant to Chapter 6, Section 7, LSO, central government and municipal authorities are obligated to supply personnel and property, provided that they have the resources that are needed and that their participation does not seriously hinder their normal activities.

With the total need of assistance in view, the actors involved in a rescue operation are to supplement and facilitate each other's work to as great an extent as possible. Each actor has personnel trained to fulfil their own organisation's mission and each actor makes its own decisions, but should do so with knowledge and consideration of the other actors' conditions and needs.

SHK's investigation has gathered information about the air rescue services, mountain rescue services and municipal rescue services carried out in connection with the accident. In addition, SHK has also examined the alerting services that are part of air traffic services. SHK's examination has mainly focused on questions concerning alerting, coordination, and access to resources, liaison and collaboration.

1.15.2 Air traffic control and alerting services

Alerting services are a part of air traffic services and are defined as "activities with a task to inform units when an aircraft needs rescue services and, to the necessary extent, to support these activities", according to the Swedish Transport Agency's regulations and general advice (TSFS 2015:51) on alerting services and air rescue services. The said regulations describe fundamental provisions for alerting services in Chapter 1, Sections 2 and 3. The Swedish Transport Agency is responsible for the oversight of air navigation services pursuant to Regulation (EU) 1034/2011[38].

At 00:19 hrs, Norway Control apprehended a distress call (Mayday) from the aircraft's crew. Norway Control responded to the call and attempted to obtain more information about the emergency situation but received no answer. The aircraft disappeared from the radar

[38] Commission Implementing Regulation (EU) No 1034/2011 on safety oversight in air traffic management and air navigation services.

screens at flight level 088. When SE-DUX sent distress messages in the form of "MAYDAY" at 00:19 hrs, the aircraft was in the airspace east of Bodø on the Swedish side of the border between Sweden and Norway. The airspace in which the aircraft was flying is part of "sector Silver", and is on permanent loan from Sweden to Norway according to a letter of agreement (LOA) between the authorities concerned. The agreement states that the alerting services in the sector concerned are to be handled by Norway. However, the agreement does not state how the Swedish legislation on alerting services and air rescue services is to be followed in the area.

At 00:19 hrs, Norwegian air traffic services (ATCC Bodø) informed Swedish air traffic services (ATCC Stockholm) that SE-DUX was in distress and was descending very quickly. The Norwegian air traffic controller also reported that the aircraft was turning to the east before it disappeared from the radar screen and asked their Swedish counterpart if they had any traffic in the area.

The air traffic controller at ATCC Stockholm who received the information called in the shift supervisor, who according to current procedures is to handle further measures with reference to the alert. At the time, the shift supervisor was outside the operators' room, and it took about five minutes before the measures commenced.

At 00:28 hrs, the shift supervisor was requested by the air rescue commander at the sea and air rescue centre (Joint Rescue Coordination Centre, JRCC) to "find out as much as you can" about SE-DUX. The shift supervisor later provided the feedback that she had not acquired any further information.

Collaboration of alerting services is regulated, inter alia, in Chapter 3, Sections 1–2, TSFS 2015:51, which states that "when the capacity of an air traffic control unit allows, the unit is to assist the air rescue centre with the collection of facts and other information of importance". This might, for example, be information on flight plan data, radar tracks and radio messages. This type of collaboration task has not been trained at ATCC Stockholm in the past ten years. TSFS 2015:51, Appendix 7 (checklist covering accidents with an unknown accident site) contains recommendations on measures that should be carried out by ATCC.

1.15.3 Air rescue services

Tasks of air rescue services

Provisions on air rescue services are found in the Swedish Transport Agency's regulations and general advice (TSFS 2015:51) on alerting services and air rescue services.

Pursuant to Chapter 4, Section 2 of the Civil Protection Ordinance (2003:789) (FSO), the Swedish Maritime Administration is responsible for air rescue services. The operational air rescue services are coordinated from the joint sea and air rescue centre (JRCC) in Gothenburg. In the accident involving SE-DUX, JRCC's task consisted in being responsible for searching for and localising the missing aircraft and in assisting other authorities responsible for rescue services. The Swedish Transport Agency is responsible for the oversight of air rescue services pursuant to Chapter 5, Section 1, FSO.

Staffing at JRCC

When the emergency situation arose, JRCC was manned by one rescue commander (air), one deputy rescue commander (air) and one assisting rescue commander (air). The assisting rescue commander (air) simultaneously maintained the task of rescue commander (sea).

Initial alerting at JRCC

Joint Rescue Coordination Centre Northern Norway (JRCC NN Bodø) informed the sea and air rescue centre in Sweden (JRCC Sweden) of the situation and at 00:26 hrs submitted information about the presumed position for the accident. The recorded conversation shows that ATCC Bodø had lost radio and radar contact with SE-DUX and that the aircraft was, at the last radar contact, over Sweden (east of Bodø) and that the air rescue operation would be coordinated by JRCC Sweden. At 00:27 hrs, JRCC adopted a concept of operations to the effect that mountain rescue and all suitable helicopter resources in the area were to be alerted.

The same clear information that had been submitted from ATCC Bodø to ATCC Stockholm was not communicated in its entirety in the call from JRCC NN Bodø to JRCC Sweden. During the first fifteen minutes after the alert, personnel at JRCC Sweden therefore devoted most of the time, in addition to the inventory of resources, to obtaining the transponder code and the last known radar position of SE-DUX.

Search area

The air rescue commander at JRCC decided to establish a limited search area since consistent information had been received that radar echoes from SE-DUX showed a rapid rate of descent within a limited area. The last radar positions coincided in an area just west of the northern part of Lake Akkajaure, near Ritsem. The search area covered the area around Lake Akkajaure and the area in the valley west of the northern part of the lake. The area around the valley was identified as an area that the pilots could have chosen to use if they had attempted to make an emergency landing of the aircraft when they were down at low altitude. The size of the search area was about 15 x 30 km. In order to ensure the aspect of flight safety within the limited search area, the rescue commander decided to request only a few airborne rescue units.

Airborne rescue units in the air rescue operation

The following is a summary of airborne rescue units that JRCC Sweden itself inventoried and units offered by JRCC NN Bodø. From the Norwegian side, assistance was offered in the search operation with, inter alia, one ambulance helicopter from Evenes and two F-16 aircraft from the Norwegian Armed Forces. At 03:07 hrs, the Norwegian F-16 aircraft were able to localise the accident site. At 03:10 hrs, the ambulance helicopter from Gällivare that was participating in the operation had also localised the accident site.

Aircraft /base	*Alert*	*Take-off time*	*In Search area*	*Other*
SAR heli Umeå (LG005)	00:30	01:49		Operation analysed separately.
Sea King Banak Norway	00:26	-		Requested by JRCC Sweden Long approach time due to weather.
Bell Bardufoss Norway	00:26	-		Requested by JRCC Sweden. Prepared for transport of Norwegian mountain rescuers.
Ambulance helicopter Evenes Norway (helidok 37)	01:43	01:59	02:22	Offered by JRCC NN Bodø. Tasked with commencing search in assigned search area.
F-16 (2 aircraft) Bodø Norway	01:43	02:18	Approx 03:05	Offered by JRCC NN Bodø. Located accident site at 03.07.
Ambulance helicopter Gällivare	00:51 via SOS Alarm	01:49 (first call)	02:13	Tasked with commencing search in southern part of Lake Akkajaure.
Police Helicopter Boden	01:16			Unable to participate in the localisation due to technical problems
Commercial helicopter	02:03			Tasked with participating in environmental rescue for municipal rescue services.

Liaison

A prerequisite for the national communication system RAKEL to function in this type of search is that the units concerned have access to RAKEL. Other possibilities for liaison in the mountains are very limited. RAKEL functioned well throughout the rescue operation in question since the ambulance helicopter from Gällivare had the ability to act as a hub in the RAKEL communication with other participant units. The SAR helicopter does not have the possibility for liaison via RAKEL, which meant that JRCC Sweden had to maintain liaison with this unit separately via satellite phone, VHF and e-mail. Liaison with the Norwegian airborne units that participated in the localisation was handled by JRCC NN Bodø.

Coordination of the air rescue operation

The air rescue commander quickly decided to call in an extra deputy rescue commander (air) for duty. This extra colleague arrived at the workplace about 30 minutes after he had been called in. The air rescue commander decided to leave the handling of media contacts during the search operation to the Swedish Maritime Administration’s staff/communications.

Pursuant to Chapter 2, Section 3, TSFS 2015:51, there shall be a management system that is to be coordinated with the actors concerned. The air rescue commander at JRCC did not use the opportunity to call in one or more collaborators from the police or the municipal rescue services in Gothenburg who could handle collaboration with their respective authorities at JRCC staff. No collaboration exercise with external collaborators for searching in a mountainous environment has been carried out at JRCC for a long time. Nor have there been any collaboration exercises with other rescue authorities in the mountains since the accident involving HAZE 01 at Kebnekaise on 15 March 2012. However, there has been some education during the spring 2016 such as three days focusing on air rescue in mountainous terrain with the cooperation of the police mountain rescue force.

The accident site was localised at 03:07 hrs by the pair of Norwegian F-16s. Both the ambulance helicopters (from Gällivare and Evenes) that were in the search area were directed to the accident site. At 03:15 hrs, JRCC received feedback that the accident site was a large hole in the ground and that there was not deemed to be any chance of survival for the pilots who were on board. The site was situated in the alpine region in the Oajevágge Valley, 25 km west of Ritsem (approximately 10 km from the border with Norway). The air rescue operation was concluded at 04:00 hrs. However, collaboration with the authorities concerned continued until 17:00 hrs the same day.

In the search area where the rescue operation was in progress, it was between 25 and 40 degrees below zero at the time, and the sun was above the horizon between 10:50 hrs and 13:05 hrs.

Collaboration JRCC NN Bodø

The personnel at JRCC Sweden have stated that they perceived collaboration with JRCC NN Bodø to function well. JRCC Sweden felt that JRCC NN Bodø had an overall grip on the ongoing search and provided support by offering useful resources. JRCC NN Bodø quickly called in air traffic personnel and other collaborators. Sweden has signed cooperation agreements with all of its neighbouring countries. The current agreement for sea and air rescue services between Sweden and Norway was signed in 2004. Article 7 of the operational agreement states the following: "After a major SAR mission, a debriefing shall be arranged as soon as possible". Such a debriefing has not been carried out.

1.15.4 Mountain rescue and municipal rescue services

Chapter 4 of the Civil Protection Act (2003:778) (LSO) contains provisions on mountain rescue. Responsibility for mountain rescue belongs to the central government, and mountain rescue operations are coordinated by the Police Authority. In the accident involving SE-DUX, it was part of the Police Authority's mission to search for and rescue persons in distress. It is also part of the Police Authority's mission in the event of an accident to attend to the remains of persons killed. However, this is not considered to constitute rescue services. The Police Authority is solely responsible for the supervision of mountain rescue pursuant to Chapter 5, Section 1, FSO.

Provisions on municipal rescue services are found primarily in LSO and FSO. Municipal rescue services are carried out by the municipality's organisation for rescue services. The municipalities are responsible for all rescue services that do not fall under central government responsibility within their geographical areas. Pursuant to Chapter 5, Section 1, LSO, the Swedish Civil Contingencies Agency (MSB) is responsible for the central supervision of municipal rescue services. The County Administrative Board also has a responsibility for the supervision of municipal rescue services within their geographical area.

In each municipality, there is to be a head of rescue services as well as one or more committees responsible for rescue services. Each municipality is to have a programme for rescue services. In extensive rescue operations, the County Administrative Board is to assume responsibility for the rescue services in the municipalities that are affected. In Norrbotten County, there is a county-wide collaboration between 10 of the municipalities in the county, and they have established an internal command function (IB) for coordination. In the accident involving SE-DUX, the rescue services in Boden, Luleå and Kiruna participated in the network coordination with experts within the organisation for county-wide collaboration. Rescue service personnel from Gällivare worked at the accident site. The mission of municipal rescue services in the accident was mainly to plan and carry out operations concerning rescue of the environment and to assist the Police Authority in its task to rescue persons in distress.

The internal command in Luleå offered help from municipal rescue services and quickly decided to support the Police Authority's mountain rescue operation at the same time as preparing for a possible environmental rescue operation that encompassed the handling of leaking aviation fuel.

The localised accident site was in mountainous terrain. The nearest navigable road ends at Ritsem (which is in Gällivare municipality). Between the accident site at Oajevagge and Ritsem is Lake Akkajaure, which was covered with thin ice at the time. It was therefore impossible to pass over the lake with vehicles. Transports to the accident site thus required helicopter resources. The helicopters that were available were the police helicopter from Boden, the SAR helicopter from Umeå, the ambulance helicopter from Gällivare and private helicopters. The SAR helicopter from Umeå was subjected to technical problems that meant that it was unable to participate in transporting rescue personnel to the accident site.

Representatives of the Police Authority and the municipal rescue services experienced difficulties with the limited transport resources with respect to prioritisation, logistics and coordination. They have stated that a special function to handle the transports would have been needed. The cold and the short time with daylight also contributed to the difficulties.

The internal command function in Luleå contacted JRCC and requested information on the quantity of aviation fuel that could be expected to be remaining at the time of the presumed accident. JRCC estimated that a maximum of two tonnes of fuel could have been remaining on board at the time when the emergency situation arose.

When the accident site had been localised, the municipal rescue services made an initial risk assessment and assessed that it was safe to approach the accident site without special protective equipment.

At the site, it was found that there was approximately 2.5 cubic metres of fluid, mainly consisting of aviation fuel, in the accident crater. The majority of the fluid was pumped up during the following day. However, when personnel had arrived at the accident site, problems arose with the pump equipment's couplings in the cold. The couplings, which are designed to be used together with flammable fluids, are manufactured in plastic and are difficult to handle when it is very cold.

1.15.5 Collaboration

Pursuant to Chapter 2, Section 4, TSFS 2015:51, the air rescue commanders are to follow established quality-assured processes that include planning and collaboration with central government and municipal rescue services. However, there are no predetermined procedures at JRCC for which type of information is to be submitted to SOS Alarm and the authorities concerned, the manner in which it is to be submitted and how it is to be updated.

The authorities and the municipalities concerned need to obtain quick information about the incident in question in order to be able to make their own assessments regarding their own operations. During the search phase, the possible area of a presumed accident, or an emergency landing in the mountains, encompassed several municipalities and one county. This meant that representatives of several agencies at different levels were simultaneously seeking information from JRCC in order to prepare their operations.

JRCC informed SOS Alarm Luleå of a "presumed accident with an unknown accident site" and requested the opportunity to use the ambulance helicopter in Gällivare (which is directed by SOS Alarm Luleå) for localisation. The question was posed at 00:51 hrs, which was 25 minutes after the alert having been received by JRCC. The information to SOS Alarm about the incident in question covered both a request for help with resources for JRCC and also information to the police, medical services and the municipalities concerned for assessment of the responsibility of the authorities and municipalities concerned. SOS Alarm communicated the information about the missing aircraft to the police and the municipal rescue services concerned.

The air rescue commander at JRCC has stated to SHK that there was a good collaboration with internal staff commanders at the municipal rescue services and at the Police Authority in connection with the accident. The police commanders responsible gave quick feedback and clear responses.

SHK's investigation shows that representatives of municipal rescue services received regular information but sought further information in order to commence their preparations for work at an expected accident site when this had not yet been localised. The representatives call for an even clearer and more standardised alert process.

1.15.6 The Swedish Armed Forces

Already at an early stage of the search operation, JRCC NN Bodø offered to assist JRCC Sweden with Norwegian air units. This encompassed, inter alia, a pair of Norwegian military aircraft of the type F-16. The Swedish Armed Forces was informed, and Headquarters processed the question of entry permission for the Norwegian units and granted such permission. The duty officer at Headquarters also took the initiative to inform and prepare Military Region North with respect to the ongoing operation. Furthermore, the Swedish Armed Forces offered possible resources for the rescue operation. However, no such resources were used.

1.15.7 *The Swedish Maritime Administration's SAR helicopters*

SAR helicopters

As mentioned above, the Swedish Maritime Administration is responsible for sea and air rescue. Such operations are coordinated by a rescue commander at JRCC, which is situated in Gothenburg. In order to carry out rescue operations, the Swedish Maritime Administration has a number of SAR helicopters (SAR – Search and Rescue) placed at five helicopter bases in Sweden. The northernmost SAR helicopter is based in Umeå. The geographical area for which the Umeå base is responsible amounts to half the Swedish air rescue region. In terms of the number of operations implemented, the Umeå base is the base that carries out the lowest number of operations.

The mission

JRCC alerted the SAR helicopter in Umeå at 00:30 hrs and informed the crew commander of what was then known. The crew immediately checked the current weather for the area from Umeå to the Norwegian border near Ritsem. At the time, there was fair flying weather around Umeå with visibility over eight km, but the forecast indicated that weather deterioration was expected. This entailed, inter alia, that even if take-off from Umeå was possible, it was not certain that it would be possible to turn back and land at the base. The crew calculated weight and balance and identified possible refuelling sites. Furthermore, snowshoes, a mountain bag for the crew and bags with personal equipment were packed.

Beyond the basic requirements for emergency and survival equipment stated in the Swedish Transport Agency's regulations (Chapter 2, TSFS 2014:61) there was no particular checklist or similar containing a description of the procedures before flight to a mountain area. The emergency crew in question had limited training and exercising in a mountainous environment in darkness. Such training and exercises are planned to be carried out in 2016 and 2017.

It took 1 hour and 19 minutes before the SAR helicopter took off from Umeå after the alert. During the time the SAR helicopter was flying towards Gällivare for refuelling, information was received that the accident site had been localised, that there were no survivors and that the rescue operation was terminated. The helicopter crew subsequently received a request to transport personnel out to the accident site but chose to carry out this task after dawn. This transport of four persons and 90 kg of equipment was commenced later but had to be discontinued at Ritsem due to technical faults. The helicopter was subsequently flown back to Gällivare for inspection, and when this had been carried out it was flown back to Umeå.

Requirements, capability and tasks in rescue operations

Provisions on Swedish SAR helicopters are found, inter alia, in the Swedish Transport Agency's regulations (TSFS 2014:61) and general advice on airborne rescue units. Concerning missions in a mountainous environment, there are supplementary directives in the Swedish Maritime Administration's document Flying Staff Information FSI 151106 "Operation in a mountain area" and in the document "Recurrent flight training in a mountainous environment", dated 11 December 2015.

The Swedish Maritime Administration's programme for sea and air rescue services dated 31 January 2013 states that the SAR helicopters have a planned operational preparedness of 15 minutes and that the resource is equipped, trained and exercised for carrying out search and localisation in severe weather conditions. Corresponding information is found in both the civilian and military AIP (Aeronautical Information Publication). The military AIP also contains supplementary information to the effect that the SAR helicopters can operate in a mountain area in daylight down to a visibility of 2 500 metres and a cloud base down to 600 feet. The corresponding values for a mountain area in darkness are visibility of 5 000 metres and a cloud base of 1 500 feet.

The fundamental task for the SAR helicopters when participating in air rescue services over land is to search for and localise a missing aircraft. The corresponding task for participation in sea and air rescue services over water is, besides search and localisation, to rescue persons in distress. Winching over land is not part of the fundamental task of air rescue over land. However, when the SAR helicopters assist other rescue service actors, there might be a need for winching over land.

The Swedish Maritime Administration has also signed a commercial agreement with the Swedish Armed Forces, which means that, if necessary, the SAR helicopters can be on stand-by for FRÄD (military preparedness for air rescue operations). This task includes rescuing pilots and passengers in distress in the event of an accident involving a military aircraft and having the capability to winch both from land and from water and also being able to carry out such missions in a mountainous environment.

Exercising and training for rescue operations in mountain areas

SHK's investigation shows that the SAR base in Umeå only has limited training and exercising for carrying out rescue missions in a mountainous environment. A greater focus appears to have been placed on training and exercising for missions over the sea, probably due to the location of the base.

Under the auspices of the Swedish Maritime Administration, the crews have undergone a three-day basic training course in mountain flying with an instructor at the beginning of 2014 and about 20 hours' solo flight training in a mountainous environment at the beginning of 2015. The crews at the SAR base in Umeå have not received any training and exercising in searching in a mountain area in darkness under the auspices of the Swedish Maritime Administration. As far as parts of the crews have experience of flying in darkness over a mountain area, this derives from previous employment. No exercises have been carried out together with Norwegian airborne rescue units, the Police Wing or ambulance helicopters in a mountainous environment.

The SAR base crews have the opportunity to plan and implement exercises by themselves when they are on duty. However, a prerequisite is that the preparedness for possible rescue operations can be maintained and that JRCC is informed of where the helicopter is. According to what has emerged in interviews with the SAR crew in question, it has occurred that requests have been expressed to conduct exercises in a mountainous environment. However, according to the crew members who have been interviewed, such requests must be accepted by the rescue commander (sea) at JRCC or the Swedish Maritime Administration's management (SAR management). Requests for exercising in a mountainous environment are not usually accepted. By comparison, the crews have had recurrent exercises of about 120 – 130 flying hours per year at sea. There are no corresponding procedures for an approval from the rescue commander (air) at JRCC or the management being required in order to be allowed to implement exercises at sea.

Statistics from the Umeå base show the following number of operations in the years 2012–2015.

Year	*Total number of conducted operations (air rescue, sea rescue and assistance to other rescue services)*	*Of which number of air rescue operations at sea*	*Of which number of air rescue operations in the mountain area*
2012	33	8	5
2013	45	2	1
2014	38	5	3
2015	48	3	1

The requirements for crews in airborne rescue units are regulated, inter alia, in Chapter 4, Sections 5–6 of the aforementioned regulation TSFS 2014:61. This states, inter alia, that the crews are to have acceptable skills for implementing SAR operations in severe weather conditions and that the training is to cover all types of SAR missions. Furthermore, it is stated that if the mission frequency is high within a certain type of SAR mission, the exercise time should in the first instance be used for exercises involving less frequent types of SAR mission.

The crews have themselves regularly pointed to the need for continuous flight training in a mountainous environment. Examples of this are found in occurrence report F1197, dated 5 June 2008, and in the compilation of experiences made after the accident involving a Norwegian military aircraft at Kebnekaise in 2012.

The document "Recurrent flight training in a mountainous environment" is dated 11 December 2015 and covers ten different examples of exercises that are to be implemented in a mountainous environment. Seven of these focus on different elements of winching, which is only required for the commercial mission that the Swedish Maritime Administration implements according to an agreement with the Swedish Armed Forces. None of the elements cover specific elements for searching in a mountainous environment in darkness.

The Swedish Maritime Administration started internal work in 2015 to improve the SAR helicopters' ability to operate in a mountainous environment. This work has continued during 2016 and it is supposed to continue during 2017 as well.

1.15.8 Emergency Locator Transmitter (ELT)

The Emergency Locator Transmitter was of the type Artex 401. No signal has been recorded from the unit.

1.16 Tests and research

1.16.1 Fuel sample analysis

As soon as the Norwegian Accident Investigation Board was informed about the accident, a fuel sample was requested from the fuelling facility that provided the fuel to the aeroplane. The sample was analysed without remarks by the fuel provider's laboratory.

1.16.2 De-icing report

SHK has taken note of the de-icing report from the departure airport. The report concludes that the aeroplane was de-iced in two steps with fluids with the correct composition.

1.16.3 Eletromagnetic interference

At the time of the accident there was low activity concerning northern light and sunspots. In the accident area there were no transmitting antennas or radars. DFDR and CVR data did not indicate any electromagnetic interference.

1.16.4 Radar and WAM data

Selected radar data was inserted into a Google Earth map. The tracks in figure 20 below are drawn with straight lines between the few recorded radar positions.

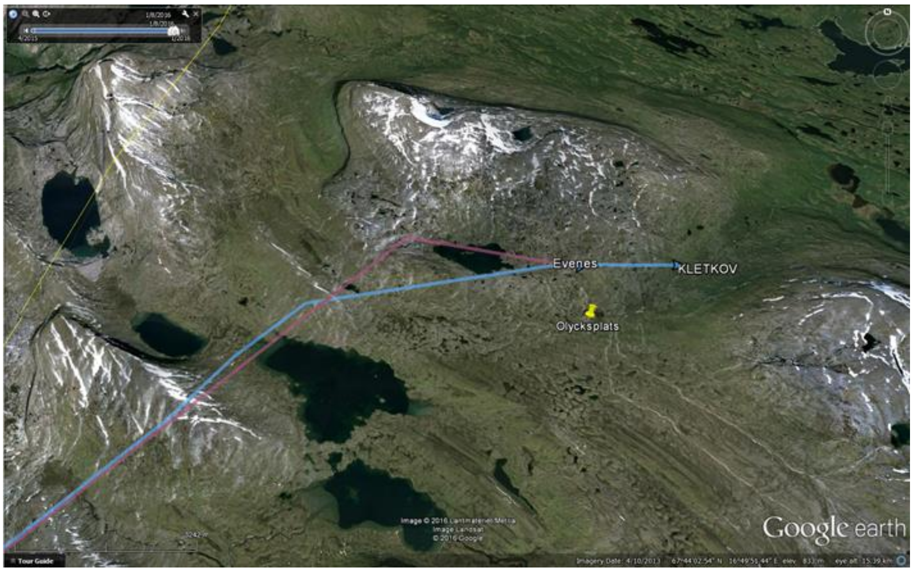

Figure 20. Radar data from Evenes and Kletkov in magenta and blue. Map: Google Earth. Map data: © Lantmäteriet Reference number R61749-13002.

WAM data from the Swedish ANS provider LFV has been inserted into a Google Earth map. According to LFV the positions have a position accuracy of 60-80 meters (Figure 21).

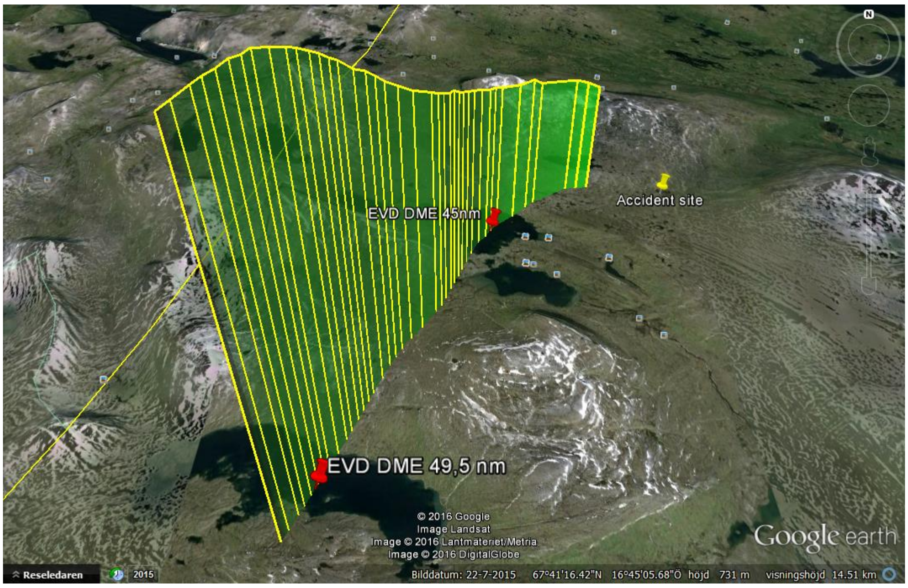

Figure 21. WAM data in Google Earth. The altitude profile and DME distances from Evenes VOR (EVD) are based on recorded DFDR-data. Map data: © Lantmäteriet Reference number R61749-13002.

1.16.5 Reference flight

One month after the accident an SHK investigator participated as an observer on a scheduled flight with one of the operator's sister aeroplanes.

With the assistance of the Norwegian SHT the loading of the aeroplane and the prestart procedures were observed. The investigator participated in the flight on the observer seat and documented operational procedures, crew cooperation and CRM.

The flight was conducted during darkness and without any moonlight on the same altitude and according to the same timetable as the accident flight.

In addition to the pilots' personal belongings 14 manuals and binders were observed in the cockpit without restraints.

During flight at cruise altitude it was possible to discern a faint outside horizon when the cockpit lighting was dimmed. In the accident area it was possible to see some illuminated towns.

During the approach briefing the PF did not hand over the controls to the PM.

The approach charts were read with lit cockpit lighting and PF focused on the approach chart while PM focused on the flight instruments and followed the briefing simultaneously on the chart.

When the cockpit lighting was on it was no longer possible to discern the outside horizon.

1.16.6 Simulator reference flight

Personnel from SHK conducted a reference flight on a certified CRJ-200 simulator used by the operator for training and OPC. The simulator is a full flight simulator (FFS) with certificate number DK-137 issued by the Danish Transport Agency.

The purpose of the session was to gain general knowledge about the aeroplane type and environment, and also to simulate different parts of the accident sequence.

All visual and audio warnings relevant to the investigation were activated and documented.

In a normal seating position both right and left PFD could be seen from both left and right seat respectively without turning of the head.

A simulated take-off and climb was performed from runway 01L at Oslo/Gardermoen Airport on the same route as the accident flight up to flight level 330. At this altitude various manoeuvers and operational tests were conducted in simulated darkness such as:

- Extreme manoeuvers in pitch and roll
- Recovery from unusual attitudes
- Overspeed
- Simulated malfunction of IRS 1 and IRS 2

- Mach trim
- Oil pressure warning

The simulator was put in freeze mode in different positions whereby instruments were documented with camera.

The simulated malfunction on EFIS was pre-programmed with a drift of the pitch angle of 8 degrees per minute, meaning 24 degrees after three minutes. This rate is 45 times slower than the drift of the pitch angle at the beginning of the event.

The caution EFIS COMP MON with associated PIT caution was activated at about 5 degrees pitch while the declutter function was activated at 30 degrees pitch angle.

In conjunction with unusual attitudes and the activation of the declutter function, it was found that the PIT and ROL cautions still were present on the PFD’s in the simulator. According to the manufacturer those cautions are not displayed in declutter mode on the aeroplane model.

1.16.7 Validation of non-compatible DFDR parameters

SHK has performed calculations in order to validate the real pitch angle as the recorded pitch angle was not compatible with the true motion of the aircraft.

The pitch angle has been recalculated based on true airspeed (TAS), altitude information and angle of attack. As the bank angle is not known and the angle of attack is used for the calculation there might be an error of a few degrees in case of large bank angles.

The chart below shows the physically probable values for the aircraft's real pitch angle and the DFDR recorded pitch angle (figure 22).

Figure 22. DFDR pitch angle (blue) and calculated pitch angle (green).

The pitch angle has also been calculated based on true airspeed and longitudinal acceleration. The recorded longitudinal acceleration has two components, the airspeed acceleration and the gravity. The recorded acceleration has been reduced by the airspeed acceleration. The result is the component of the gravity which gives the pitch angle.

This calculation corresponds mainly with the previous one.

In parallel, the aeroplane's manufacturer also performed similar calculations under the supervision of TSB Canada. These calculations provided results that are largely consistent with the calculations made by SHK. The manufacturer's calculations also included simulations to reproduce probable values for magnetic heading and roll angle.

The calculations show that the DFDR-recorded roll angle started to deviate from the aeroplane's calculated real roll angle about 6 seconds after the start of the event. The roll angles thereafter show a certain consistency and are definitely deviating after another 13 seconds.

Furthermore, the calculations show that the DFDR recorded magnetic heading started to deviate from the calculated magnetic heading after approximately 11 seconds (figure 23).

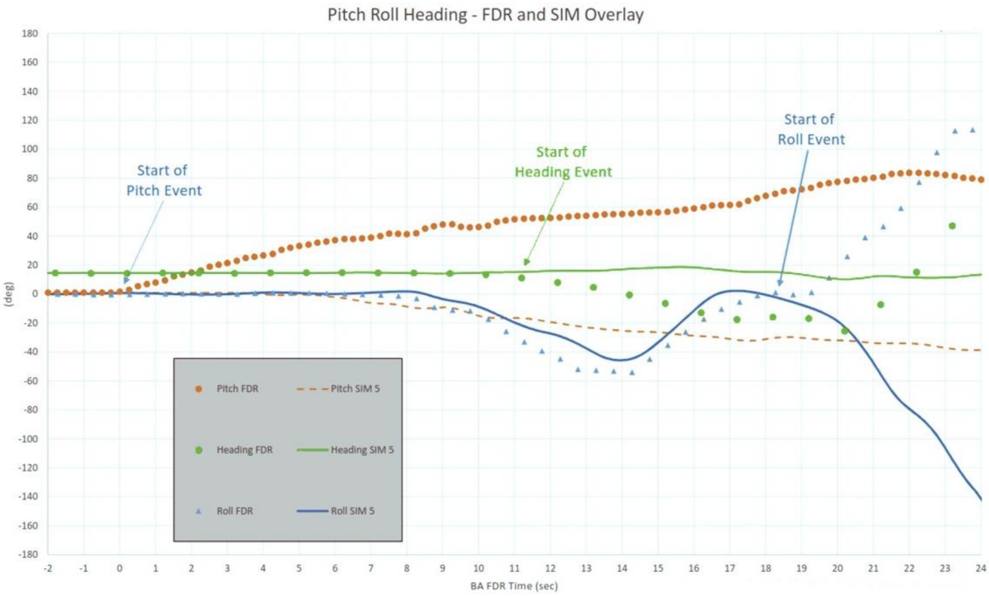

Figure 23. Discrepancy between DFDR recorded values and simulated real values.

1.16.8 Simulations

Two simulations were made to illustrate the sequence.

One simulation was made by the aeroplane manufacturer, the other by the manufacturer of the PFD devices.

Aeroplane manufacturer simulation

The aeroplane manufacturer utilized a six degree of freedom simulation model, which has the aerodynamic characteristics of the aeroplane, with DFDR and CVR data to estimate the pitch, roll and heading during the event.

The simulation was made using the information recorded on the DFDR regarding the aeroplane's control surfaces (elevator, aileron, spoileron, rudder and stabilizer) to calculate pitch and roll angle and magnetic heading. To correct measurement errors and assumed data between the recorded data of the DFDR, other data such as Gz, angle of attack, indicated airspeed and altitude have been used. Furthermore, bank angle warnings were used to correct the calculated roll angle.

The accuracy of the simulation deteriorates over time due to the accumulation of errors.

The simulation of pitch angle is more precise than that of roll angle because there are more recorded parameters which are dependent on the pitch angle.

The start time of the simulation is set to **t0**, corresponding to the time of the first change in the recorded pitch angle. Initial conditions for the simulation correspond to the aircraft conditions at the beginning of the accident sequence.

The simulation shows a very good conformity up to Mach 0.85. Between Mach 0.85 and Mach 0.9 there is still a very good conformity, although some adjustments have been made. After the exceedance of V_D and / or M_D there is no aerodynamic data for the aeroplane. Furthermore, sensors and systems for speed and altitude measurement are not calibrated for values exceeding V_{DF}[39] and M_{DF}[40].

The initial 10 seconds of the simulation (after **t0**) provide a very good conformity with the DFDR parameters. This indicates that the aircraft's initial nose-down movement was initiated only by the movements of the elevator and stabilizer and that the aeroplane responded normally to rudder movements without any external or abnormal interference as e.g. load shift.

The simulations do not reflect the exact reality. The aim is to create a picture of the most probable course of events and to illustrate this to create a better understanding. The results are presented in the analysis section of the report.

PFD manufacturer simulation

The PFD manufacturer simulation consisted of two PFD displays that were representative of the aeroplane’s configuration at the time of the accident, see figures 25 to 29. It has been assumed that recorded DFDR data concerning pitch and roll angles (data from IRU 1) were displayed on PFD 1 (left). The PFD 2 (right) shows data calculated by the aeroplane manufacturer as explained above.

1.16.9 IRU of the type LTN-101

There are approximately 9 100 systems with IRU of the type LTN-101 installed on different aeroplanes, inter alia, Airbus A319, A320, A321, A330, A340, Bombardier CRJ series, CL 604 and SAAB 2000.

1.16.10 IRU history and research

LTN-101 (GNIRU[41])	IRU 1	IRU 2
Part number	465020-04000402	465020-04000401
Serial number	0343	0253
Installed	16 Jan 2015	20 May 2013
Manufactured	1994	1994

The different part numbers indicate that the software was not the same in the two installed units. According to the TC-holder’s maintenance data it is not approved to install this configuration with different software. The most significant difference in the software is an update of the magnetic variation. However, the difference in the software is not considered significant to the event according to the manufacturer of the units.

[39] V_{DF} – Demonstrated flight diving speed.
[40] M_{DF} – Demonstrated flight diving speed expressed in Mach number.
[41] GNIRU – Global Navigation Inertial Reference Unit, refers to an IRU without air data function.

At the time of installation, IRU 1 had an approval for return to service by an authorized release certificate.

From the time of installation until the accident, no malfunctions have been recorded.

The manufacturer of these units has tried, through various tests, to recreate the malfunction supposedly originating from IRU 1. The tests have been conducted with the aim of reproducing the recorded DFDR data.

A complicating factor was that no NVM (Non Volatile Memory) from IRU 1 was found after the accident meaning that the number of possible scenarios is almost infinite. Laboratory tests of reference systems have been conducted and confirm that the performance of the attitude output was in accordance with design specifications. Five simulations were performed with different erroneous inputs. An analytical test was also performed. None of the simulations or the analytical test had any correlation to recorded DFDR data. No mechanical failure or software error has been detected during the tests.

According to the IRU manufacturer, the contractual reliability requirements for these units specify as acceptable 35 undetected failures per one million flight hours.

According to the aeroplane manufacturer, the expected reliability of these units is better than 5.7 undetected failures per one million flight hours. This matches the IRU manufacturer's failure prediction.

There are no scheduled maintenance requirements concerning the IRU in the maintenance program approved by the Swedish Transport Agency.

The manufacturer Northrop Grumman has stated that fault reporting seldom contains detailed error descriptions regarding faulty units received for maintenance. The information is quite frequently written by the operators without any detail (e.g. failed unit without any other information). The lack of such detailed information could complicate troubleshooting and impair improvement of components.

1.16.11 Interviews

Interviews have been conducted with 11 of the operator's 13 pilots on the aeroplane type, including the Chief Pilot. Interviews were also conducted with simulator and line training instructors.

The pilot who served as pilot in command on the aeroplane during the two sectors preceding the accident crew's sectors has stated that nothing abnormal was observed.

1.16.12 *Flight without external visual references*

Spatial orientation and the sense of balance

Spatial orientation is defined in aviation as the ability to perceive one's own aircraft position and movement relative to the surface of the earth. Information about the head and body position and movement relative to the surroundings involves primarily three senses: the vision, the somatosensory system and the sense of balance (vestibular system).

Under normal circumstances the vision provides an intuitive idea of one's own motion relative to the surroundings and on the direction of gravity. Such visual information is generally reliable and therefore has great significance for the human capacity for spatial orientation and postural control (balance). The somatosensory system, with receptors for push and pull (proprioceptors) in the skin, muscles, joints and internal organs contributes to the experience of how the body is oriented relative to gravity. Inner ear labyrinth includes two receptor systems: the semi-circular canals, which reacts to head movements, and otolith organs who perceive linear accelerations and the head position in the gravitational field.

It is impossible to perceive the aircraft's position by only using the otolith organs, or the body sensation (somatosensory). When flying without external visual references pilots are therefore totally dependent on their instruments. An important part of instrument flight training is to learn to ignore disorientation.

Spatial disorientation

Spatial disorientation is a term used to describe a variety of incidents occurring in flight in which the pilot fails to sense correctly the position, motion or attitude of the aircraft or themselves in relation to the surface of the earth.

A number of factors have been identified which may predispose a pilot to spatial disorientation, or increase the difficulty of using the intellect and visual instruments to recover from an undesired aircraft state:

1. Factors that deprive the pilot of reliable external visual references, such as darkness;

2. Certain flight manoeuvers, such as bunts resulting in low or negative Gz;

3. Pilot-related factors, such as distraction or high levels of stress;

4. Aircraft related factors, such as instrument error;

5. Factors that call for attention, such as abnormal instrument indications and warnings.

A bunt manoeuver results in negative G-values that may cause an inversion illusion, meaning a feeling of being upside down (figure 24).

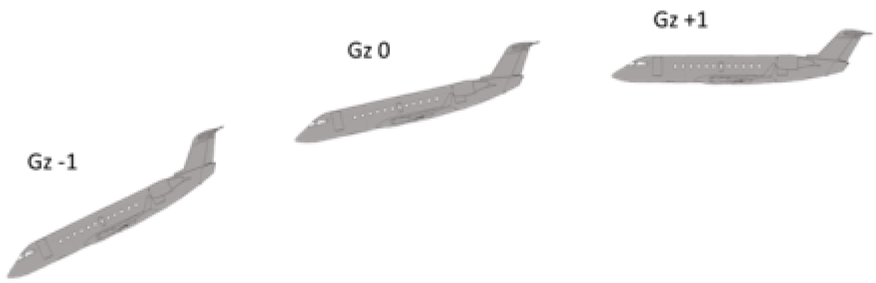

Figure 24. Illustration of a bunt manoeuver.

There are three types of spatial disorientation:

Type I. Unrecognized (the pilot does not consciously perceive any manifestations of disorientation)

Type II. Recognized (the pilot is aware of a false orientation perception, but is able to adequately manoeuver the aircraft)

Type III. Incapacitating (the pilot recognizes that he or she is disoriented but is not capable of adequate manoeuvring)

1.16.13 Surprise effect

In an automated process the surprise effect, caused by unexpected changes, can affect or delay rational behaviour. Upset prevention and recovery training aims, inter alia, to reduce the negative effects caused by unexpected changes.

ICAO defines surprise as:

The emotionally-based recognition of a difference in what was expected and what is actual.

1.17 Organisational and management information

1.17.1 The operator

West Atlantic Sweden AB is an aviation company engaged in commercial cargo air transport. The operator had a valid Swedish AOC permit No. SE.AOC.0015 issued by the Swedish Transport Agency. The operator used, inter alia, three aeroplanes of the type CRJ200-PF mainly for postal cargo flights.

The operator's manuals

SHK has reviewed the content of the operator's manuals.

Among the manuals used by the operator, AFM[42], OM-B/CRJ, FCOM[43] 1 and 2 and QRH[44] are directly related to the operation of the aeroplane.

Concerning the PFD-units, SHK has not found any descriptions in the operator's manuals regarding the functions unusual attitude, declutter (non-essential information is removed from the display) or the chevron symbols (red arrows indicating direction of recovery). However, these items are described in the manufacturer's Pilot Reference Manuals (PRM). The operator did not have access to PRM and the operator's training organization did not use the manuals.

SHK has not found any description for immediate actions due to abnormal or emergency indications such as MASTER WARNING or MASTER CAUTION.

The operator has published callouts pertinent to immediate action items. These callouts shall be expressed in a command tone during flight as this will make the operations more efficient.

SHK has not found any procedure or callouts pertinent to automatic autopilot disengagement.

There are no published callouts for abnormal procedures such as EFIS COMP MON. It is only stated that the first pilot observing a Master Caution shall reset the switch light.

SHK has reviewed the operator's SMS manual. SMS (Safety Management System) is described by the operator as a systematic approach to managing aviation safety including the necessary organisational structures, accountabilities, policies and procedures, and includes any management system that, independently or integrated with other management systems of the organisation, addresses the management of safety.

The SMS manual also includes description of reactive, proactive and predictive hazard identification.

SHK has not found, at the time of the accident, any information pertinent to TEM (Threat and Error Management) or UPRT (Upset Prevention and Recovery Training) in the operators training documentation. UPRT was not mandatory at the time of the accident.

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[42] AFM – Airplane Flight Manual.
[43] FCOM – Flight Crew Operating Manual.
[44] QRH – Quick Reference Handbook.

1.17.2 *The manufacturer*

Bombardier Aerospace is a Canadian aeroplane manufacturer and is the type certificate holder for the aeroplane model in question.

The aeroplane's manuals

The operator's manuals give reference to the following aeroplane's manuals published by Bombardier consisting of:

- AFM which contains, inter alia, contains limitations, procedures and performance data for the operation.
- FCOM Volume 1 which, inter alia, contained descriptive information about the aeroplane's systems.
- FCOM Volume 2 which contained, inter alia, detailed descriptions of normal, abnormal and emergency procedures. The abnormal procedure EFIS COMP MON is described in this manual.
- QRH is a small binder which is placed in an easy accessible location to both pilots. It contained, inter alia, checklists for emergency and abnormal procedures. The abnormal procedure EFIS COMP MON was also found in the QRH.

SHK has not found any procedure with associated callouts pertinent to automatic autopilot disengagement in the aeroplane's manuals.

SHK has not found any description in the aeroplane's manuals for immediate actions for warnings or indications such as MASTER WARNING or MASTER CAUTION.

The manufacturer has published a training manual called Pilots Reference Manual (PRM). PRM includes description of standard procedures for abnormal and emergency procedures. For example, the applicable procedure for audio and light cautions and warnings such as MASTER WARNING/CAUTION is described in the PRM.

There are no regulatory requirements to provide a PRM. According to the manufacturer, the PRM is only used for training purposes.

1.17.3 *EASA*

EASA regulations do not specify any requirements for callouts for abnormal or emergency procedures.

EASA introduced requirements for Upset Prevention and Recovery Training (UPRT) on 4 May 2016.

UPRT is further described in section 1.18.3.

1.17.4 The Swedish Transport Agency

The Swedish Transport Agency has the oversight regarding the operator and has reviewed and accepted the operator's manuals. The review means that the manuals are checked for compliance with regulations.

The Swedish Transport Agency cannot impose requirements that go beyond the applicable regulations, e.g. EASA OPS.

1.18 Additional information

1.18.1 Training

Flight crew performance in the cockpit can be divided into skill-, rule- and knowledge-based behaviour. Skill-based behaviour is habitual and often occurs with rapid response automatically and without further consideration. Rule based actions are based on what is stored in long-term memory, for example: if the stop bar turns red, I will stop. The rule-based behaviour comes in when the situation does not allow the pilot to react with intuitive response to a specific situation. Knowledge-based action begins when a problem does not match the information stored in long-term memory, and that leads to the rule-based behaviour. The knowledge-based action generally contributes to greater creativity in connection with problem solving.

In the event that there is a lack of knowledge, knowledge-based actions may constitute a source of error. The management and outcome of critical and unexpected situations is therefore largely dependent on the training and regular practice of the procedures for such situations. Recurrent and repetitive simulator training have an important role. Such training contributes to skills that in critical situations can be applied almost instinctively.

1.18.2 CRM

CRM (Crew Resource Management) is defined as follows according to EASA, GM1 ORO.FC115:

(a) CRM is the effective utilisation of all available resources (e.g. crew members, aircraft systems, supporting facilities and persons) to achieve safe and efficient operation.

(b) The objective of CRM is to enhance the communication and management skills of the flight crew member concerned. Emphasis is placed on the non-technical knowledge, skills and attitudes of flight crew performance.

1.18.3 Upset Prevention and Recovery Training

Upset Prevention and Recovery Training was not mandatory at the time of the accident. Such training is mandatory since 4 May 2016.

According to the operator the training had started at the time of the accident but was not yet completed for all flight crew members and not for the flight crew in question.

The training recommends that the following callouts with response should be used for the recovery of developed upset with nose high attitude.

The first who observes the position analyses and confirms the development of the situation by declaring "Nose High."

The monitoring pilot (PM) confirms or denies the situation. The PM monitors speed, attitude and altitude during the events and calls out further changes.

In the situation of low nose attitude the corresponding callout "Nose Low" is described in the EASA guidance material.

However, it has not been possible to find any callouts in the preventive measures, before the upset is developed, concerning faulty indications on attitude indicators.

1.18.4 Actions taken

The operator

The operator has taken the following actions since the time of the accident:

- Upset Prevention and Recovery Training (UPRT) has been implemented.
- Fatigue Risk Management (FRM) has been partly implemented.
- Simulator training on simulated instrument error with automatic autopilot disconnection has been implemented.
- Training on Threat and Error Management (TEM) and monitoring skills has been implemented.

The aeroplane manufacturer

The manufacturer has taken the action to revise the FCOM and introduce a declutter function description.

The Swedish Maritime Administration

The Swedish Maritime Administration has, after the accident, taken the following measures concerning JRCC Sweden.

- Three theme days have been conducted in the spring of 2016 for all staff at the JRCC focusing on mountain rescue, with the participation of the police mountain rescue.

- A new training base for search and rescue in the mountains has been developed in order to increase the skills of rescue leaders at the JRCC.

- A new instruction "Information sharing, task parallelism" has been produced in order to improve cooperation between the Maritime Administration and other actors in a rescue operation.

- Planning to conduct a joint exercise on search and rescue in the mountains in 2017.

- Planning to conduct staff exercises with the external collaborators during 2017-2019.

1.19 Special methods of investigations

Not applicable.

2. ANALYSIS

2.1 The aeroplane's state at the start of the event

The simulation and calculations in Section 1.16.7 and 1.16.8 clearly show that the aircraft was structurally and aerodynamically intact at the beginning of the event, and at least until V_D and M_D was exceeded. This is also supported by the fact that all flight control surfaces and the aeroplane's four corners were found at the accident site. No evidence of an inflight break-up has been found.

The simulation and the calculations that have been performed confirm the aeroplane's actual motion. These motions are coherent with the recorded control surfaces deflections. The simulation also indicated that there was no cargo shift.

The movements of the flight control surfaces were consistent with attempts to correct the aeroplane's attitude based on the attitude information recorded by the DFDR. As the autopilot was disconnected, the most probable scenario is that the manoeuvring of the aeroplane was performed by the flight crew.

2.2 History of the flight

2.2.1 Preconditions

The preconditions for the flight were good. The crew had altogether several years of experience with this sector and the forecasted weather did not indicate any difficulties.

The flight planning was carried out according to standard operational procedures, and the aircraft's technical status did not indicate any abnormalities.

2.2.2 *Flight preparations*

Preparations before start, such as loading, refuelling and de-icing followed normal routines. The pilots' actions and communication followed established procedures according to SOP.

The flight controls check that was observed through video, CVR and DFDR indicates that all flight control surfaces were moving in the correct direction with full deflections.

The taxiing to the runway has been observed in the same way without any indications of discrepancies.

2.2.3 *The take-off, departure, climb and cruise*

The initial part of the flight, including the take-off, the departure, the climb and the cruise did follow normal routines and actions in accordance with established procedures.

After the aircraft reached cruising altitude some conversations of a private nature in English were heard. No language barriers were observed, which indicates that the communication between the pilots was not hampered or deteriorated for reasons of language.

The occurrence took place at 00:20, at a time when performance deterioration can occur due to fatigue.

Sudden unexpected events that the individual has not previously experienced increase the demands on cognitive ability.

The investigation has found deficiencies in the pilots' communication and difficulties in handling the situation. This type of difficulty of cognitive character can be seen during fatigue.

SHK have noted that the pilots' duty hours did not exceed the flight time limitations. However there is no information available about the crew's actual sleep time during the days preceding the accident.

Therefore no conclusions regarding fatigue or how fatigue may have affected the course of events is drawn from those risk factors.

Although there are risk factors related to fatigue present, for instance working during night hours, SHK in this event regard the cognitive-emotional surprise effect that the pilots were subjected to, to outweigh the possible state of fatigue.

Immediately before the beginning of the event the crew was proceeding with the briefing for the approach to Tromsø. The fact that the manoeuvring of the aircraft was not handed over to the PM may have contributed to a less than optimal instrument monitoring during the briefing. However this has probably not affected the course of the event since the pitch angle deviation was detected within seconds.

2.2.4 The sequence of the event

Introduction

To facilitate the understanding of the sequence of events SHK has chosen to denote the start time of the event to **t0** seconds instead of the actual time 00:19:20 hrs.

The figures of the PFD 1 below show what was recorded by the DFDR, while the figures of the PFD 2 is a result of the simulation as described in section 1.16.8. The analysis is therefore based on the assumption that the information displayed on PFD 1 was the same information as recorded by DFDR and that the information displayed on PFD 2 is consistent with the first 23 seconds of the simulation. This part of the simulation has been considered to have a very good conformity with the actual event.

There were no DFDR records about the PFD 2 and the standby instruments. SHK makes the assumption for the analysis that these units were functioning normally.

The first five seconds

At the start of the event the aeroplane was in level flight at flight level 330, with an indicated airspeed of 275 knots. The autopilot was engaged.

The start of the event was the first recorded change of pitch angle from 1.0 to 1.7 degrees at time **t0**.

The approach briefing was in progress, which probably meant that the pilots partly focused their attention on the approach charts. Since the maps must have been illuminated to be read, and other cockpit lighting could have been lit, the pilots' night vision had probably deteriorated. This meant that external visual references were virtually non-existent. The pilots were therefore entirely dependent on the aircraft's attitude indicators.

The pilot in command’s first strong expression *"What (*)"* was recorded after approximately two seconds. The expression is interpreted as a surprise effect due to the rising pitch angle displayed on PFD 1. It also indicates that the attitude indicator was monitored by the pilot in command at this stage.

SHK’s opinion is that the pilot in command at this moment was exposed to a surprise effect because of the difference between what was expected and what was displayed. As the left PFD displayed information that was not consistent with the aircraft's actual movements and external visual references were absent the pilot in command was subjected to a degradation of his spatial orientation.

The figure 25 below shows the information that is believed to have been displayed on PFD 1 and 2. The Pitch angle on the left PFD was about 15 degrees but unchanged on the right PFD.

Since the difference between the units exceeded 4 degrees, the PIT symbol was displayed flashing in yellow. No audible warning (Master Caution) had yet been recorded which is likely due to the delay which is built into the system. The activation of the PIT display shall coincide by design with an EFIS COMP MON caution on the EICAS display. The flight director indicator went down to give control commands to lower the nose of the aircraft as the autopilot was in the altitude hold mode called Altitude Track.

Figure 25. Left and right PFD at **t2**.

At **t3** the autopilot most likely disconnected automatically due to differences in the pitch servo commands. The disconnection meant that the AP display in the attitude indicators upper left corner shifted from solid green to flashing red indication and the audio warning "Cavalry Charge" was activated.

The lack of a prescribed procedure and standard callouts for automatic autopilot disconnection might explain why this was not commented upon or acknowledged by the crew. Furthermore, it was not made clear verbally that any of the pilots had assumed manual control of the aeroplane.

At **t4** the pitch angle on the left PFD reached 30 degrees and the unit went into declutter mode which means that the PIT caution and the Flight Director symbol disappeared and that a red chevron appeared. The right unit was still displaying information without declutter as before (see figure 26 below).

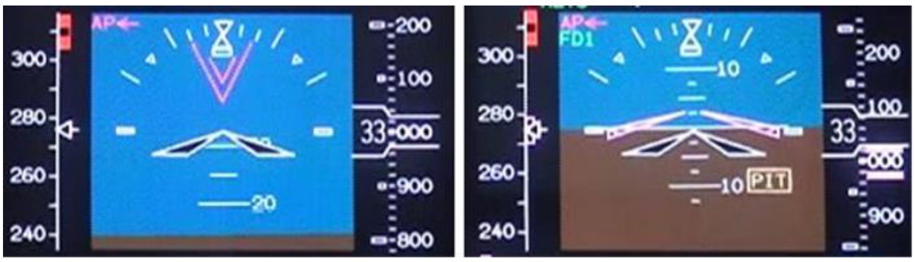


Figure 26. Declutter on left PFD at **t4**.

Almost simultaneously the audio warning Single Chime was activated with a delay due to the autopilot disconnect warning that had priority. No verbal acknowledgement from either pilot was heard on the CVR recordings. Both elevators moved towards nose down while the left control wheel trim switch was activated indicating that the pilot in command, who was the PF, was manoeuvring the aircraft.

The action is probably due to several factors. Pilots have learned since basic instrument training to rely on their instruments, which may explain the pilot in command's actions. The fact that the pitch angle displayed on the left PFD was high and increased rapidly in combination with the display of the red chevrons requesting pitch down inputs probably contributed to the pilot's instinctive reaction to act according to the displayed unusual attitude.

The high pitch rate increase displayed on PFD 1 in combination with the display of the red chevrons may have created a mental state that led to a cognitive tunnel vision where other visual and auditory information could not be included or were deliberately ignored.

The crew was subjected to an unexpected change in the aircraft's automation level with automatic disconnection of the autopilot, which occurred during a flight phase where you normally do not expect any changes.

The situation indicates that the pilots initially became communicatively isolated from each other. A contributing factor to this was the lack of regular training of procedures for unusual attitudes. Nor were there any clear rule-based behaviour to fall back upon. Therefore, the situation evolved into problem solving and improvisation, thus a knowledge-based behaviour.

In the 3 seconds period between **t2** and **t5**, the pilot in command faced an increase of the displayed pitch from 15 to more than 30 degrees, an autopilot disconnection and a PFD declutter with the display of red chevrons requesting pitch down inputs to exit the displayed unusual attitude in pitch.

Within those 3 seconds, from a visual point of view, the PIT symbol was only displayed at most four times, blinking and always on a blue background. The angle between the flight director (FD) bar and the aircraft symbol was fixed (as soon as the pitch angle reached 15 degrees, FD was displayed stationary at the bottom of the attitude display). The brown portion and the horizon line were also stationary in the bottom part of the of the attitude indicator. Thereafter the PFD declutter meant that the red chevrons appeared.

The number of changes of displayed information in such a limited time, together with the delayed single chime heard between the repetitive cavalry charge, may explain the difficulties to understand what was happening and to implement a clear and consistent mutual problem solving.

By this time, the pilots probably had different perceptions of the situation because of differences in the display on the respective attitude indicator. A basic prerequisite for the crew to jointly cope with the situation was sharing the same perception, or mental model of the situation. In order to achieve a common perception, or mental model, one needs to communicate with each other.

From 5 to 13 seconds

As a result of elevator and trim movement the recorded angle of attack decreased, the aircraft began to descend and the vertical acceleration Gz was changing towards negative values.

At **t9** the co-pilot exclaimed a strong expression which was his first recorded verbal reaction since the beginning of the event. This was answered by the pilot in command with the same expression.

The flight crew communications during the flight, up to the beginning of the event, indicate an open dialogue with mutual forgiveness and exchange of information. SHK therefore concludes that the lack of communication until now in the course of events was not based on any hierarchical conditions that impaired the communication. However, the silence of the crew is a clear indication of a lack of understanding of the current situation and an inability to verbally communicate to troubleshoot the abnormal situation. Variations in G-load probably also affected communication ability.

The recorded roll angle now started to deviate from the calculated angle (see figure 27). The vertical acceleration was negative which caused the activation of the warnings Triple Chime and Engine Oil. At the same time irregular sounds were heard over a period of several seconds. SHK considers that the sounds originated from loose objects, such as files and manuals hitting the roof area in the cockpit due to the negative G-load.

In this situation, the pilots probably experienced discomfort by lifting up from their seats and being pushed against their seat belts while the legs and arms were subjected to an upward force. It is also possible that the pilots in this situation had a feeling of being upside down, a so-called inversion illusion. However, the roll angle at this moment indicates that the pilot in command did not act according to such an illusion.

A few seconds after the negative G-load onset, between **t9** and **t12**, the co-pilot’s trim switch was activated while an unexplained roll to the left occurs. The reason for this might have been the co-pilot’s grabbing on the control wheel during negative G-load.

Figure 27. Start of diverging Roll Angle at **t9**.

At approximately **t13** the Pitch Angle on the right side PFD reached minus 20 degrees which meant that the declutter mode now was activated on this side (see figure 28 below). The co-pilot exclaimed the first operational callout "Come up". At about the same time the warning for stabilizer movement, Stab Trim Clacker, was activated and another Triple Chime sounded which was cut-out by two Bank Angle warnings.

Figure 28. Declutter mode on right PFD at **t13**.

The situation at this time meant that the crew were presented with two contradictory attitude indicators with red chevrons pointing in opposite directions. At the same time none of the instruments displayed any comparator caution.

None of the pilots verbally referred to the standby horizon. This can be explained by the complex situation facing the flight crew due to variations in G-load and a great number of audio and visual cautions and warnings. This probably further contributed to cognitive tunnel vision and focus on each on-side attitude indicator.

From 13 to 23 seconds

From that time, efforts were made by the crew to restore the communication. At **t15** the pilot in command exclaimed his first operational callout asking for help, which was answered by the co-pilot by calling out different roll directions.

The pitch down inputs were made in response to the red chevrons on the left PFD. At the same time the right PFD displayed red chevrons in the opposite, pitch up direction. This meant that the pilots did not have a common understanding of the situation and were subjected to spatial disorientation.

The efforts to regain control were not based on rational decisions or communication, but probably the result of trained flight control inputs movements guided by the erroneous information.

The aircraft left its flight envelope at **t17** when V_{MO} was exceeded, which activated the overspeed warning. Recorded vertical G-load now turned to positive rates. At the same time irregular sounds were recorded once again. SHK finds it probable that these sounds were due to loose objects falling back down towards the cockpit floor.

At **t23** the Mach number had increased to 0.90 which is significantly higher than M_{MO} (M_{MO}=0.80 at the current altitude).

The speed and attitude in combination with the spatial disorientation of the flight crew at this point meant that the possibilities to recover from the loss of control of the aeroplane now were minor.

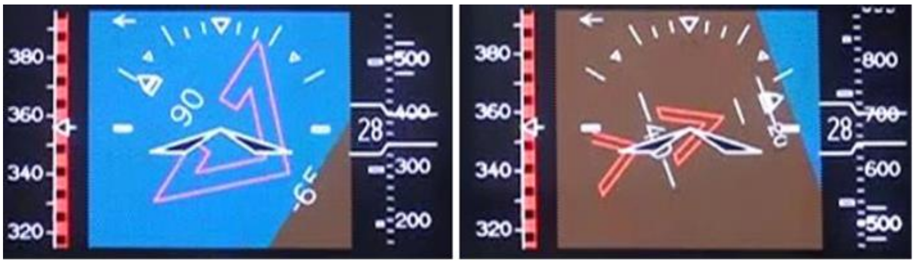


Figure 29. Display of the simulation at **t22**.

From 24 seconds to impact

During this period of the sequence altitude and speed recordings as well as data from the simulation are not reliable due to the lack of information about aerodynamic data and instrument calibration. SHK has therefore opted not to further analyse this part of the sequence.

However, according to the CVR recordings, the flight crew transmitted distress calls and tried to recover from the aeroplane upset during this period of time.

2.3 The human machine interface for the PFD units

2.3.1 The declutter function of the PFD units

The declutter function means that only roll and pitch angle is displayed on the attitude indicator part of the PFD units during unusual attitudes. This meant that the comparator monitor indication disappeared from the PFD 1 and PFD 2 at an early stage of the sequence.

The purpose of clearing the PFD units from unnecessary information, and thereby providing the pilots with a better display of the situation during unusual attitudes, is easy to understand. It is however more difficult to understand why indications related to instrument errors are removed.

It is possible that such an indication could have helped the pilots to identify the erroneous PFD display. Furthermore, there is a delay of more than 1 second between the caution message and the associated single chime. In case of multiple cautions and warnings, the audio alerts may be desynchronized with the visual messages, causing confusion in the flight crew's troubleshooting.

Furthermore, as the system does not know which PFD displays the correct parameters when EFIS COMP MON triggers, no declutter function should be automatically performed in this case to avoid the removal of information useful to troubleshoot the situation.

SHK considers that the decluttering of the caution indications on the PFD displays during unusual attitudes is a weakness in the system design.

2.3.2 Simulator reference flight

The simulator flight performed by SHK proved that the comparator caution was not removed from the PFD during unusual attitudes in the simulator.

Training experience with comparator cautions displayed during unusual attitudes might contribute to trust in a decluttered faulty attitude indicator.

System discrepancies between a simulator and the aeroplane mean that the quality of flight education and training is downgraded. This is particularly true during unusual attitudes and other malfunctions that are not normally trained in the aeroplane.

2.4 Communication and training

2.4.1 Communication

The crew cooperation was working with "challenge and response" until the start of the event. Thereafter, the communication between the flight crew members ceased. The following 12 seconds consisted of single sided expressions of surprise. The lack of communication prevented a mutual rational analysis and evaluation of the situation.

The operator prescribes callouts for emergency procedures with immediate action items. These callouts shall be made in a command tone. There are no callouts for abnormal procedures, neither are such callouts prescribed by EASA.

SHK considers that clear and distinct communication between crew members is essential to maintain situational awareness and thereby optimize flight safety. The authorities and organizations publishing regulations in the matter should therefore ensure that a general system of initial standard calls is introduced in commercial aviation for clear, precise and bidirectional communication between crew members in abnormal, emergency as well as unusual and unexpected situations.

2.4.2 Training

The management of emergency and abnormal procedures requires callouts which are rehearsed during training and recurrent training. This gives the flight crew members a better opportunity to maintain a functioning communication in emergency and abnormal situations.

Upset prevention and recovery training was implemented by EASA in 2016. SHK notes that callouts are not prescribed in the oversight authorities document for the prevention portion of the training, which is an insufficiency that should be corrected.

2.5 Malfunction of the IRU

2.5.1 The malfunction of IRU 1

The only plausible explanation to the erroneous data recorded by DFDR is an internal malfunction of IRU 1.

SHK and the manufacturer of the unit have searched for similar events without finding any similar IRU malfunctions.

The manufacturer of the unit performed physical tests and software tests without being able to reproduce the scenario.

Figure 23 shows that only the pitch angle information was erroneous until the aeroplane was changing its roll angle. Until that time, only the pitch gyro was needed to calculate the pitch angle. When the aeroplane started to turn, both the gyros for pitch and yaw were needed to calculate pitch angle and heading. The roll angle will change if a movement in yaw is introduced when the pitch angle is other than zero.

This means that, upon manoeuvring in several dimensions simultaneously, the roll and heading information will become erroneous if the pitch gyro provides erroneous information. The errors in ground speed can be explained by the erroneous calculation of the heading angle.

The internal continuous self-test accepted the attitude parameters as valid thereby providing the erroneous information to both PFD 1 and DFDR.

When SSM (Sign Status Matrix) sets an error on the attitude parameters from IRU 1 the system shall display a failure flag on PFD 1. This means that the attitude information is removed and replaced by a red “ATT” flag. The failure of the self-test to discover the error can be logical if the failure consisted of an error from a single gyro unit within the system’s limitations.

2.5.2 Actual configuration of the IRUs

The aeroplane’s two IRUs had different part numbers and thereby different software. Such a setup is not approved, which meant that the installation of IRU 1 was not a correct maintenance action. However, this is not considered to have had any impact on the sequence of the event.

2.5.3 Fault reporting on aircraft

During the investigation it has emerged that fault reporting sometimes is written in a less detailed manner. This can lead to information about faults not being correctly identified by component workshops.

The deficiencies may be at different levels in the reporting chain from the operator to the maintenance workshops.

Requirements ensuring a more detailed reporting at all levels could consequently contribute to increase flight safety.

2.6 Rescue services

2.6.1 Alerting services

The rescue services legislation is national, and Sweden's neighbouring countries have different legislations. The Swedish airspace in which SE-DUX was flying when the emergency situation arose was on permanent loan from Sweden to Norway, but the agreement regulating the airspace in question does not state how the Swedish legislation on alerting services and air rescue services is to be followed in the area. According to SHK, agreements concerning airspace sectors that are on loan between Sweden and other states should encompass, or refer to, procedures for alerting services that clarify what applies.

When the emergency situation arose within ATCC Stockholm's area of responsibility, the shift supervisor was, according to current procedures, to handle any further measures. However, these measures were delayed due to the shift supervisor being outside the operators' room when the emergency situation arose, and there were no procedures for how the measures were to be handled in their absence. There should be procedures to enable an alerting message about a critical situation to be submitted immediately to the air rescue centre concerned so that valuable information is not delayed.

When the shift supervisor at ATCC Stockholm was requested to "find out as much as you can" about SE-DUX, there was a lack of clarity on what was intended. Chapter 3, Sections 1-2, TSFS 2015:51 states that "when the capacity of an air traffic control unit allows, the unit is to assist the air rescue centre with the collection of facts and other information of importance". According to the air rescue centre, this might for example be information on flight plan data, radar tracks and radio messages.

The coordination task between the Swedish Maritime Administration (JRCC) and the relevant air traffic control units (including ATCC) should be developed so as to achieve expertise on which search tasks these can provide to the air rescue centre. The collaboration has not been exercised at ATCC Stockholm in the past ten years. This should be corrected since the ability to handle alerting tasks otherwise risks to deteriorate.

2.6.2 Air rescue services

There are no predetermined procedures at JRCC for which type of information is to be submitted to SOS Alarm and the authorities concerned, the manner in which it is to be submitted and how it is to be updated. If the air rescue commander were to have a log system at their disposal through which he or she automatically shares essential information with SOS Alarm and the relevant authorities responsible for rescue services, this would reduce the workload at JRCC. At the same time, SOS Alarm and the relevant authorities responsible for rescue services would, through faster, similar and continuously updated information, gain better conditions for carrying out their tasks. The investigation raises coordination issues similar to those treated in the investigation of the Hercules accident at Kebnekaise in 2012 (SHK report RM2013:02) and in the investigation of the sailplane SE-UPT at Pirttivuopio in 2015 (SHK report RL2016:3). After the accident, JRCC changed the log system to a system that in the future may be used for information sharing with SOS Alarm. In addition, a routine for information sharing at parallel rescue operations has been developed.

The air rescue commander at JRCC did not use the opportunity to call in one or more collaborators from the police or the municipal rescue services in Gothenburg who could handle collaboration with their respective authorities at JRCC staff. Staff work with collaborators from other authorities responsible for rescue services in JRCC staff needs to be developed.

If the ambulance helicopter had been occupied with another mission and had not been able to participate in the operation, RAKEL communication would probably not have been possible, or would have been very limited. According to the Swedish Maritime Administration, RAKEL installations will commence in autumn 2016 and all seven SAR helicopters will have the equipment installed in autumn 2017.

The analysis shows that there is a lack of training, exercises and safety procedures for rescue swimmers who are part of the SAR helicopter’s crew for operating optimal in a mountainous environment. Even if it not part of the Maritime Administration's mission to have alpinist trained rescue swimmers, their duties in a mountainous environment may sometimes be comparable with tasks performed by the Alpine Mountain Rescue Group, which has extensive training for being able to carry out their missions.

The Maritime Administration should consider whether the SAR-base during parts of the winter season could be moved closer to the mountains. It would facilitate the conditions for training and flying in the mountains by day and night, and facilitate cooperation exercises with other actors in the mountains, all of which would contribute to a better ability to carry out rescue operations in the mountains. During the winter season it is normally less activities and rescue operations at sea in the northernmost waters.

2.6.3 Mountain rescue/municipal rescue services

When the aircraft had been located, the Police Authority as well as the municipal rescue services were, informed about this and that it was clear that there were no survivors. Hence the rescue efforts conducted thereafter had a different character than they would have had if life-saving efforts would have been needed. The issues mentioned above about improvements in coordination with the JRCC consequently did not have a decisive impact.

Representatives of the Police Authority and the municipal rescue services experienced difficulties with the limited transport resources with respect to prioritisation, logistics and coordination. Similar problems have been expressed in other investigations of accidents where the road network has been limited. The authorities concerned need to develop their cooperation regarding this matter.

2.6.4 Emergency Locator Transmitter

The high energy impact probably meant the ELT-unit received such damage that it did not send out any signals.

2.7 Overview of the occurrence

During the flight, a malfunction occurred on one of the aeroplane's inertial navigation units (IRU 1). The erroneous information from the IRU 1 was displayed on the left primary flight display (PFD 1) and recorded on the flight data recorder (DFDR).

The malfunction occurred when the crew was performing the approach briefing, which meant that attention was divided between two simultaneous tasks. This probably contributed to the surprise effect.

This meant that the pilot in command's PFD indicated a sharp increase in pitch angle although the aeroplane was in level flight. Moreover, this led to the automatic disconnection of the autopilot. At the same time, the co-pilot's PFD displayed information which was consistent with the aeroplane's actual attitude.

The aircraft was equipped with three independent attitude indicators, one of which indicated incorrect values. Thus there were two working attitude indicators that could give the crew the correct attitude information to operate the aircraft safely. However, this requires that the crew has the ability to identify the malfunction and to rationally evaluate the situation.

The PIT miscompare indication on the PFD displays, supposed to inform the crew about the miscompare between PFD 1 and PFD 2 was probably activated, but was displayed on PFD 1 for a very short period of time. By design, the miscompare indication, along with other information considered secondary, disappears at unusual attitudes to allow the crew to focus on a more limited set of information.

The crew was trained to rely on their instruments, in the absence of external visual references. This may explain the reflexive manoeuvring that induced the rapid descent of the aeroplane when the red chevrons appeared.

The rapid change of the pitch angle indicated on PFD 1, the severe changes in G-loads that the crew was subjected to and the large number of audio and visual warnings probably contributed to the pilots focusing on their on-side PFD units. These conditions, the fact that there was no training method for effective communication in an unexpected or abnormal situation and that the crew therefore had not practised this contributed to the crew not being able to jointly identify the problem in time.

The crew began to communicate operatively with each other after 15 seconds. After another two seconds the maximum allowable speed was exceeded.

At **t23** the aeroplane's speed and attitude was far outside the design envelope, which in combination with the spatial disorientation of the flight crew meant that the possibilities to regain control of the aircraft were limited.

The erroneous indication that occurred must be considered so unusual that one cannot anticipate and prepare for the specific malfunction. However, it is possible to foresee that unusual and unexpected events of various kinds can occur.

For this reason it is essential that flight crews use systematic and well-rehearsed procedures for handling unusual and unexpected situations.

The current flight operational system lacked essential elements which are necessary. In this occurrence a system for efficient communication was not in place.

The safety of commercial air transport over the years has gradually increased through the introduction of various procedures and training. In recent years focus has been, inter alia, on unreliable airspeed indication and UPRT.

Since it is not possible to anticipate all possible scenarios, it might not be effective to introduce a new specific training like, for example, unreliable attitude indicator. General methods should be in place to be able to solve unpredictable situations.

With this background in mind, SHK considers that a general system of initial standard calls for the handling of abnormal and emergency procedures and also for unusual and unexpected situations should be incorporated in commercial aviation.

This means a system of initial standard calls for clear, precise and bidirectional communication between the pilots. The table below gives a few examples to clarify SHK's suggestions.

Event	**Action**	**Callout**
Autopilot automatic disconnect	Cancel warning Take control	"Autopilot off" "I have control" with confirmation from other pilot
EFIS COMP MON caution	Cancel caution	"Master Caution" "EFIS COMP MON" with confirmation from other pilot
Pitch increase indication on PFD	(Compare attitude if not confirmed)	"Nose high" with confirmation from other pilot
Stall at high altitude	Take control	"Stall, I have control" with confirmation from other pilot

SHK is aware that this is already in place within some aircraft manufacturers' manuals and some operators. However, it is surprising that this is not a standard throughout the commercial air transport industry.

3. CONCLUSIONS

3.1 Findings

a) The crew was qualified to perform the flight.

b) The aeroplane had a Certificate of Airworthiness and valid ARC.

c) The crew actions were according to Standard Operating Procedures (SOP) until the beginning of the event.

d) The aeroplane's flight control system operated normally.

e) IRU 1 produced erroneous parameters (pitch, roll and heading) without any indication of a fail message.

f) The erroneous recorded parameters from IRU 1 were displayed on PFD 1.

g) After autopilot disconnect, the aeroplane remained in level flight until the elevators commanded the aeroplane pitch down.

h) The aeroplane was aerodynamically and structurally intact at least until VD and MD was exceeded.

i) No evidence of an inflight break-up has been found.

j) Information about declutter, unusual attitude and chevrons concerning the PFD units could only be found in the manufacturer's PRM.

k) Information about the removal of comparator cautions in declutter mode could not be found in any manual.

l) The declutter function, concerning the comparator cautions, was different between the simulator and the aeroplane.

m) No callouts were found in the operator's manuals for the abnormal procedure EFIS COMP MON, neither are such callouts prescribed by regulations.

n) There are no regulatory requirements for standard callouts for abnormal or unusual situations.

o) No signal was recorded from the ELT.

p) The air rescue operation was conducted by the Swedish Maritime Administration's joint sea and air rescue coordination centre (JRCC Sweden).

q) The accident site was localised by units from the Norwegian Armed Forces.

r) Coordination and communication between JRCC and air traffic control units can be improved.

s) Coordination and communication between JRCC and other authorities responsible for rescue services can be improved.

t) The time from the alert until the SAR helicopter in Umeå took off towards the accident site was 1 hour and 19 minutes.

u) The SAR crews in Umeå lack sufficient practise, training, and procedures to have a satisfactory ability to carry out rescue operations in the mountainous area.

3.2 Factors as to cause and contributing factors

The accident was caused by insufficient operational prerequisites for the management of a failure in a redundant system.

Contributing factors were:

- The absence of an effective system for communication in abnormal and emergency situations.
- The flight instrument system provided insufficient guidance about malfunctions that occurred.
- The initial manoeuver that resulted in negative G-loads probably affected the pilots' ability to manage the situation in a rational manner.

3.3 Factors as to risk

The fact that fault descriptions regarding aircraft and its components are reported in a less detailed manner might imply that the faults will not be identified and corrected in an efficient way. This can in turn lead to a flight safety issue as, for instance, intermittent faults cannot always be detected by general tests.

4. SAFETY RECOMMENDATIONS

ICAO is recommended to:

- Ensure that a general system of initial standard calls for the handling of abnormal and emergency procedures and also for unusual and unexpected situations is implemented throughout the commercial air transport industry. *(RL 2016:11 R1)*

EASA is recommended to:

- Ensure that a general system of initial standard calls for the handling of abnormal and emergency procedures and also for unusual and unexpected situations is implemented throughout the commercial air transport industry. *(RL 2016:11 R2)*

- Ensure that the design criteria of PFD units are improved in such a way that pertinent cautions are not removed during unusual attitude or declutter modes. *(RL 2016:11 R3)*

Transport Canada is recommended to:

- Ensure that a general system of initial standard calls for the handling of abnormal and emergency procedures and also for unusual and unexpected situations is implemented throughout the commercial air transport industry. *(RL 2016:11 R4)*

- Ensure that the design criteria of PFD units are improved in such a way that pertinent cautions are not removed during unusual attitude or declutter modes. *(RL 2016:11 R5)*

FAA is recommended to:

- Ensure that a general system of initial standard calls for the handling of abnormal and emergency procedures and also for unusual and unexpected situations is implemented throughout the commercial air transport industry. *(RL 2016:11 R6)*

- Ensure that the design criteria of PFD units are improved in such a way that pertinent cautions are not removed during unusual attitude or declutter modes. *(RL 2016:11 R7)*

The Swedish Transport Agency is recommended to:

- Ensure that providers of air traffic control units guarantee procedures to enable an alerting message about a critical situation to be submitted immediately to the air rescue centre concerned. *(RL 2016:11 R8)*

- Ensure that providers of air traffic control units train and exercise relevant personnel so that they can assist the air rescue centre in accordance with current regulations.
(RL 2016:11 R9)

- Ensure that the Maritime Administration secures that all crews maintaining preparedness for SAR missions in mountainous areas fulfil the requirements on capability to perform appropriate search tasks. *(RL 2016:11 R10)*

The Swedish Maritime Administration is recommended to:

- Develop the coordination between the sea and air rescue coordination centre (JRCC) and concerned air traffic control units (including ATCC) so that air traffic control units' staff becomes familiar with which facts and other information they may need to assist JRCC. *(RL 2016:11 R11)*

- Ensure that rescue commanders and assistant rescue commanders are given regular training and exercising in staff work with collaborators from other authorities responsible for rescue services and organisations in JRCC. *(RL 2016:11 R12)*

- Produce a basis for, and perform, training and exercising in searching in a mountainous environment for SAR crews maintaining preparedness in a mountainous environment in both daylight and darkness. *(RL 2016:11 R13)*

- Review procedures so as to minimise the time for preparations ahead of take-offs with SAR helicopters. *(RL 2016:11 R14)*

The Swedish Accident Investigation Authority respectfully requests to receive, by **13/03/2017** at the latest, information regarding measures taken in response to the safety recommendations included in this report.

On behalf of the Swedish Accident Investigation Authority,

Jonas Bäckstrand   Nicolas Seger

Appendices

Appendix 1: FDR plots.

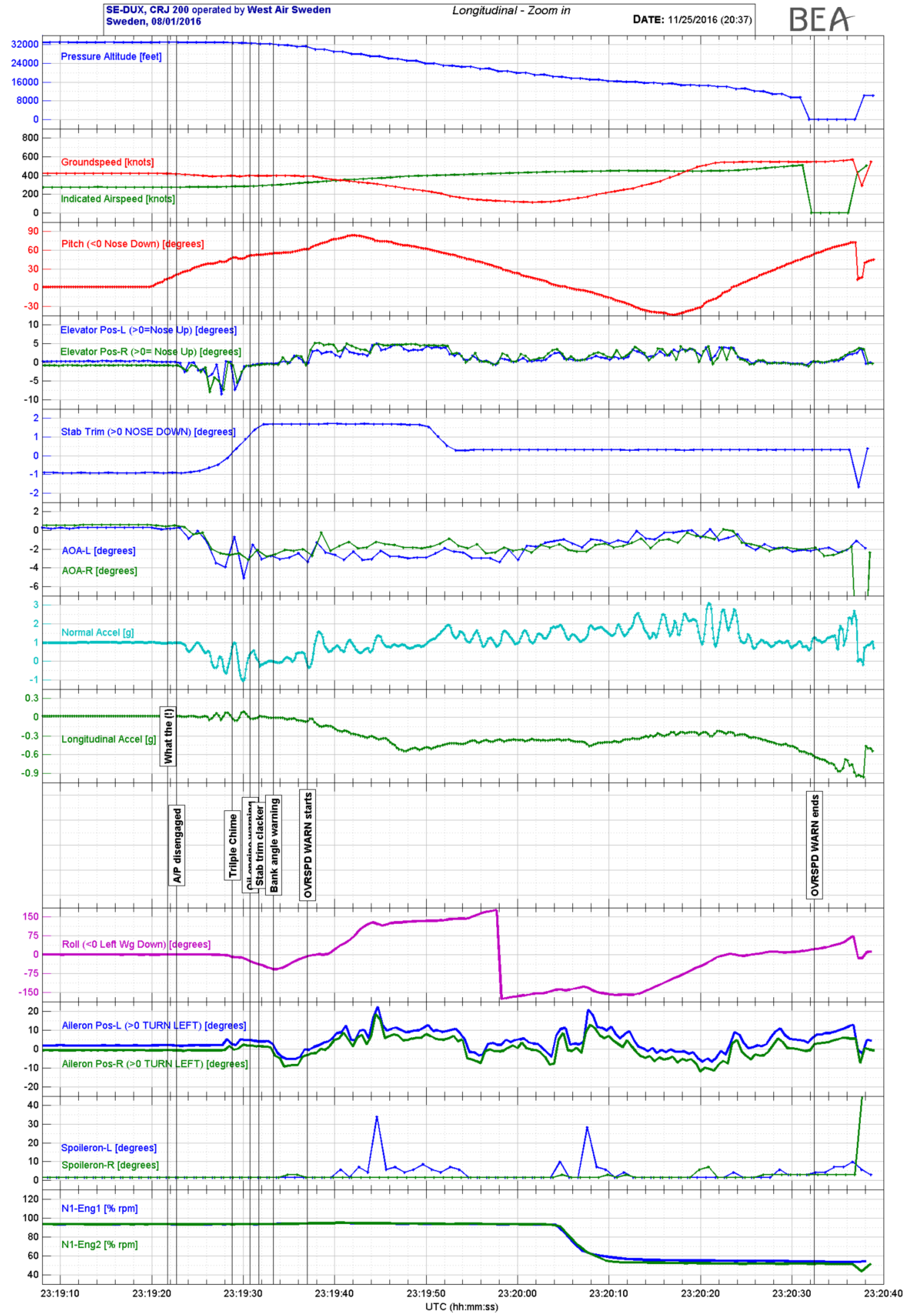
Appendix 2: CVR transcript.

Appendix 1

FDR plots with selected parameters from top to bottom in the graph as follows:

Pressure altitude, ground speed*, indicated airspeed, pitch angle*, elevator position left/right, stabilizer trim, angle of attack left/right, normal acceleration (G), longitudinal acceleration (G), rollangle*, aileron position left/right, spoileron left/right, N1 speed for left/right engine.

* Those parameters are not compatible with the aeroplanes motion.


SE-DUX, CRJ 200 operated by West Air Sweden
Sweden, 08/01/2016
Longitudinal - Zoom in
DATE: 11/25/2016 (20:37)
BEA
Pressure Altitude [feet]
32000
24000
16000
8000
0
800
600
400
200
0
Groundspeed [knots]
Indicated Airspeed [knots]
90
60
30
0
-30
Pitch (<0 Nose Down) [degrees]
10
5
0
-5
-10
Elevator Pos-L (>0=Nose Up) [degrees]
Elevator Pos-R (>0= Nose Up) [degrees]
2
1
0
-1
-2
Stab Trim (>0 NOSE DOWN) [degrees]
2
0
-2
-4
-6
AOA-L [degrees]
AOA-R [degrees]
3
2
1
0
-1
Normal Accel [g]
0.3
0
-0.3
-0.6
-0.9
Longitudinal Accel [g]
What the (!)
A/P disengaged
Triple Chime
Stab trim clacker
Bank angle warning
OVRSPD WARN starts
OVRSPD WARN ends
150
75
0
-75
-150
Roll (<0 Left Wg Down) [degrees]
20
10
0
-10
-20
Aileron Pos-L (>0 TURN LEFT) [degrees]
Aileron Pos-R (>0 TURN LEFT) [degrees]
40
30
20
10
0
Spoileron-L [degrees]
Spoileron-R [degrees]
120
100
80
60
40
N1-Eng1 [% rpm]
N1-Eng2 [% rpm]
23:19:10
23:19:20
23:19:30
23:19:40
23:19:50
23:20:00
23:20:10
23:20:20
23:20:30
23:20:40
UTC (hh:mm:ss)

Appendix 2 CVR transcript.

Legend: SV - Synthetic voice
(*) words that could not be interpreted
( ) word of uncertain interpretation
(!) strong expression
italics: communications with ATC

Time UTC	Pilot In Command	First Officer	ATC	Remarks, sounds and warnings
23.19.22	What (!)			
23.19.23				Continuous Cavalry Charge
23.19.24				Single Chime
23.19.28				Irregular sound
23.19.29				Triple Chime
23.19.29		What (!)		
23.19.30	What (!)			
23.19.30				SV: Engine oil
23.19.31				Warning: Stabilizer trim clacker
23.19.33		Come up		
23.19.33				SV: Bank angle
23.19.35	Come on, help me, help me, help me			
23.19.35		Turn right		
23.19.35				SV: Bank angle
23.19.36		What		
23.19.37				Warning: Overspeed (Clacker)
23.19.37	Help me, help me			
23.19.38		Yes, I’m trying		
23.19.40		Turn left, turn left		
23.19.40				SV: Bank angle
23.19.41				Continuous Cavalry Charge warning ends
23.19 42				SV: Bank angle
23.19 43		Turn left		
23.19.44				Single Chime
23.19.44		No		
23.19.45				Single Chime

Time UTC	Pilot In Command	First Officer	ATC	Remarks, sounds and warnings
23.19.50		*Mayday, mayday, mayday Air Sweden 294*		Transmit switch not activated
23.19.53		*Mayday, mayday, mayday*		
23.19.53			*294*	
23.19.54		*Mayday, mayday, mayday Air Sweden 294*		
23.19.55				Single Chime
23.19.57				Single Chime
23.19.57		*We turning back, mayday, mayday*		
23.19.59	Mach trim			
23.20.00			*294, mayday 294*	
23.20.00				Single chime
23.20.01		Trim, trim a lot		
23.20.04				SV: Bank Angle
23.20.06		Turn left, turn left		
23.20.06				SV: Bank Angle, Bank Angle
23.20.08			*294*	
23.20.09				SV: Bank Angle
23.20.09		*Mayday, mayday, mayday, we turning back*		
23.20.14	We need to climb, we need to climb			
23.20.15		Yeah, we need to climb		
23.20.15				SV: Bank Angle
23.20.16			*(*)*	
23.20.16		Turn left, turn left		
23.20.17				SV: Bank Angle
23.20.17	No, continue right, continue			
23.20.19				SV: Bank Angle

Time UTC	Pilot In Command	First Officer	ATC	Remarks, sounds and warnings
23.20.19	Continue right			
23.20.20		Ok, (*)		
23.20.22	No, help me, help me please			
23.20.22				SV: Bank Angle
23.20.23		I don’t know, I don’t see anything		
23.20.23				SV: Bank Angle
23.20.24		I think you are the right to correct		
23.20.25	Ok			
23.20.26	Ok, ok, ya			
23.20.28	(!)			
23.20.29				SV: Bank Angle
23.20.31		What (!) (*)		
23.20.32				Overspeed warning (Clacker) ends
23.20.33				SV: Bank Angle
23.20.35	(*)			
23.20.35				SV: Bank Angle
23.20.36	(*)			
23.20.37				Single Chime
23.20.37				End of recording