Accident Investigation Board Norway

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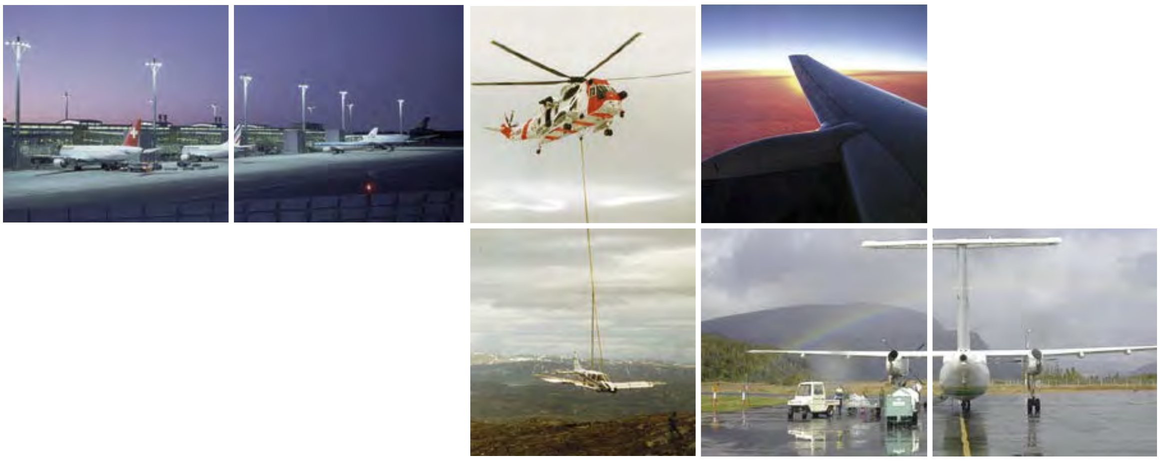

REPORT ON THE SERIOUS AIRCRAFT INCIDENT DURING APPROACH TO KITTILÄ AIRPORT IN FINLAND (EFKT) ON 26 DECEMBER 2012 WITH A BOEING 737-800, LN-DYM, OPERATED BY NORWEGIAN AIR SHUTTLE ASA

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

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

Photos: AIBN and Trond Isaksen/OSL

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REPORT ON SERIOUS AIRCRAFT INCIDENT

Aircraft:	Boeing Commercial Airplane Group, Boeing 737-800 NG (B737-8JP)
Nationality and registration:	Norwegian, LN-DYM
Owner:	SMFL Aircraft Capital Corporation B.V., the Netherlands
User:	Norwegian Air Shuttle ASA
Crew:	2 pilots + 4 cabin crew members
Passengers:	173
Incident site:	ILS approach to runway 34 at Kittilä airport, Finland (EFKT) (approximately 67° 30’ N 025° 00’ E)
Incident time:	Wednesday, 26 December 2012, 10:28 hours

All hours stated in this report are local Finnish time (UTC + 2 hours) unless otherwise indicated.

NOTIFICATION ABOUT THE INCIDENT

The incident was reported in writing to the Civil Aviation Authority - Norway via Norwegian Air Shuttle's reporting system on the morning of 27 December 2012. This was within the 72-hour deadline. Due to the fact that the incident occurred in Finland and was thus not reportable to the Norwegian investigation authority, the Accident Investigation Board of Norway (AIBN) was not notified.

The airline contacted the Finnish Safety Investigation Authority and reported the incident via e-mail on 8 January 2013. The Finnish Safety Investigation Authority first asked the Finnish Transport Safety Agency (CAA) whether they had received a report on the incident, and then the report received by the Civil Aviation Authority - Norway was requisitioned and submitted to the Safety Investigation Authority. Based on the content of the report, the Finnish Safety Investigation Authority contacted AIBN the same day (8 January 2013). The main rule is that the nation where an incident occurs, “State of Occurrence”, in this case Finland, shall conduct the investigation. The Finnish and Norwegian accident investigation authorities agreed that it would be most appropriate for the investigation to be conducted by AIBN.

In accordance with ICAO Annex 13 (*Aircraft Accident and Incident Investigation),* AIBN sent notifications of initiated investigation to the US' National Transportation Safety Board (NTSB), the European Aviation Safety Agency (EASA), Finland's Safety Investigation Authority and the Civil Aviation Authority - Norway. The NTSB and Finnish Safety Investigation Authority appointed accredited representatives who have assisted in the investigation.

SUMMARY

During approach to Kittilä (EFKT) in Finland on 26 December 2012, LN-DYM, a Boeing 737-800 NG on Norwegian Air Shuttle's (NAS') air service NAX5630 from Helsinki airport (EFHK), came close to stalling. The outcome of a stall would most likely have been catastrophic, primarily because the elevator system at that time did not function normally. The elevator system worked only at a ratio of 1:250.

De-icing was carried out prior to departure in order to remove about 25 cm of snow that had settled on the aircraft. The departure and flight en route to the destination were normal. During the approach to Kittilä, the aircraft was established on the localizer at 4 421 ft (AMSL) with flaps 5 configuration, and the autopilot as well as autothrottle were engaged. As the aircraft was in the process of intercepting the glide slope, the elevator trim started to pitch the nose up. This trim continued for 12 seconds. At the same time, the aircraft started to unintentionally ascend while the autothrottle commanded full engine thrust. Both pilots eventually pushed the elevator control column with full force, but the aircraft's nose continued to pitch up to an angle of +38.5° before slowly decreasing. The aircraft's speed dropped to 118 kt (Calibrated Airspeed, CAS) and the Angle of Attack (AOA) reached a maximum of approximately 25°. The aircraft was thus close to stalling. The aircraft's autopilot was disengaged just after the aircraft's nose angle was at its highest. Control over the aircraft was slowly regained. A new approach was carried out without additional problems.

AIBN's investigation has uncovered that de-icing fluid had ingressed the tail section and frozen on three or four of the input cranks for the aircraft's two elevator Power Control Units (PCUs) and thus prevented them from functioning as intended. The investigation has documented that, even after the introduction of new de-icing procedures from Boeing, considerable amounts of fluid and humidity are entering the tail section (Tail Cone Compartment) during de-icing. AIBN questions whether this satisfies the certification requirements for the aircraft type. AIBN believes there is a need for measures that prevent ice formation on the input cranks and thus reduce the risk of blocking normal elevator function on the Boeing 737 series.

The investigation has also uncovered a potential for improvement in relation to registration of inquiries received by the company's center for maintenance management, and the fact that LN-DYM continued to operate after the incident.

Three safety recommendations are proposed in connection with the submission of this report.

1. FACTUAL INFORMATION

1.1 History of the flight

1.1.1 Preparations for the flight

1.1.1.1 LN-DYM, a Boeing 737-800 NG, was scheduled to fly Norwegian Air Shuttle's air service NAX5630 from Helsinki airport Vantaa (EFHK) to Kittilä airport (EFKT) in the morning hours of 26 December 2012.

1.1.1.2 Due to the Christmas holiday, the aircraft had not flown since 23 December. Over the course of these three days, the aircraft had been outdoors in snow showers, relatively heavy wind and cold. About 25 cm of snow had settled on the aircraft.

1.1.1.3 A routine inspection ("A1 & C check") had been carried out by licensed aircraft technicians. In the morning, prior to departure, the crew carried out a routine "Pre Flight Inspection" and other preparations for the flight. The aircraft had no technical remarks prior to departure.

1.1.1.4 After the passengers and cargo were on board, LN-DYM left the terminal at 08:47 hours, on schedule. The aircraft was taxied to a dedicated area (Apron 8) to undergo extensive de-icing.

1.1.1.5 The de-icing started at 08:58 hours and close to 3 000 litres of de-icing fluid was used to remove snow and ice (see Appendix D for supplementary details).

1.1.1.6 In addition to the ordinary pre-departure checklists, the pilots used the company checklist in connection with the de-icing. The checklist is based on standard procedures from the aircraft manufacturer, Boeing. The mentioned checklist e.g. entailed that the pilots, prior to de-icing, must set the horizontal stabilizer trim at the flight deck to maximum forward position. In addition Norwegian has implemented a procedure that the pilots after de-icing shall move the control column three times between full forward and aft position. The flight data recorder shows that the control column was moved between the forward and aft position five times. The commander has explained that the control column moved normally, without noticeable abnormal resistance. The de-icing was complete at 09:13 hours.

1.1.1.7 The temperature at the airport at that time was -17 °C (1 °F).

1.1.1.8 The aircraft then took off from Vantaa at 09:21 hours (35 minutes after it started taxiing). The crew has explained that the departure, en route flight at flight level FL360 and initial approach were without incident. The commander was piloting the aircraft (Pilot Flying, PF), while the first officer was monitoring the flight (Pilot Monitoring, PM / Pilot Not Flying, PNF).

1.1.2 Approach to Kittilä

1.1.2.1 Based on the weather information, the pilots were prepared to pass a temperature inversion[1] during the approach to Kittilä, and this was discussed.

1.1.2.2 One hour and 8 minutes after departure, the aircraft was approaching Kittilä and the pilots had established the aircraft on the localizer for the instrument landing system (ILS) for runway 34. When the aircraft passed 4 421 ft AMSL (approximately 3 800 ft above threshold elevation RWY 34), it had the following configuration:

Flaps:	5°
Landing gear:	Retracted
Autopilot:	Engaged and with approach mode engaged channel A in use
Autothrottle:	Engaged
Engine power:	Approximately 30 % N1 and N2
Nose angle:	+ 1.5°
Localizer:	Established
Airspeed:	193 CAS
Wing Anti-ice:	On

The following conditions were in effect:

Icing conditions:	Moderate
Outside temperature:	-12 °C SAT (-7 °C TAT), 10 °F SAT (-19 °F TAT)
Temperature at airport:	-22 °C, -8 °F

1.1.2.3 The aircraft was positioned to intercept the glide slope from below. As it was in the process of establishing itself on the glide slope, the electrical stabiliser trim started to engage. On the Boeing 737, it is normal for the stabiliser trim to engage for a few seconds in such a phase, but this time the trim continued for 12 seconds in the nose-up direction[2]. The electric trim changes the position of the entire horizontal stabiliser. Before this happened, the aircraft's nose angle had been +1.5°, but as a result of the new trim setting, the aircraft's nose rose considerably.

1.1.2.4 This caused the airspeed to rapidly decline, thus engaging the aircraft's autothrottle system at full engine power. On the Boeing 737, the engines are located below the aircraft's lateral axis (pitch). Full engine power caused the aircraft's nose to rise further,

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[1] A temperature inversion is a meteorological phenomenon in the atmosphere where the temperature increases proportional to the altitude and no longer decreases proportional to altitude, which is usually the case.

[2] When the trim is active, it gives a characteristic sound and a white marking on the trim wheel is easily visible.

with associated further loss of airspeed. Figure 1 shows an excerpt from the aircraft's flight data recorder in connection with the incident.

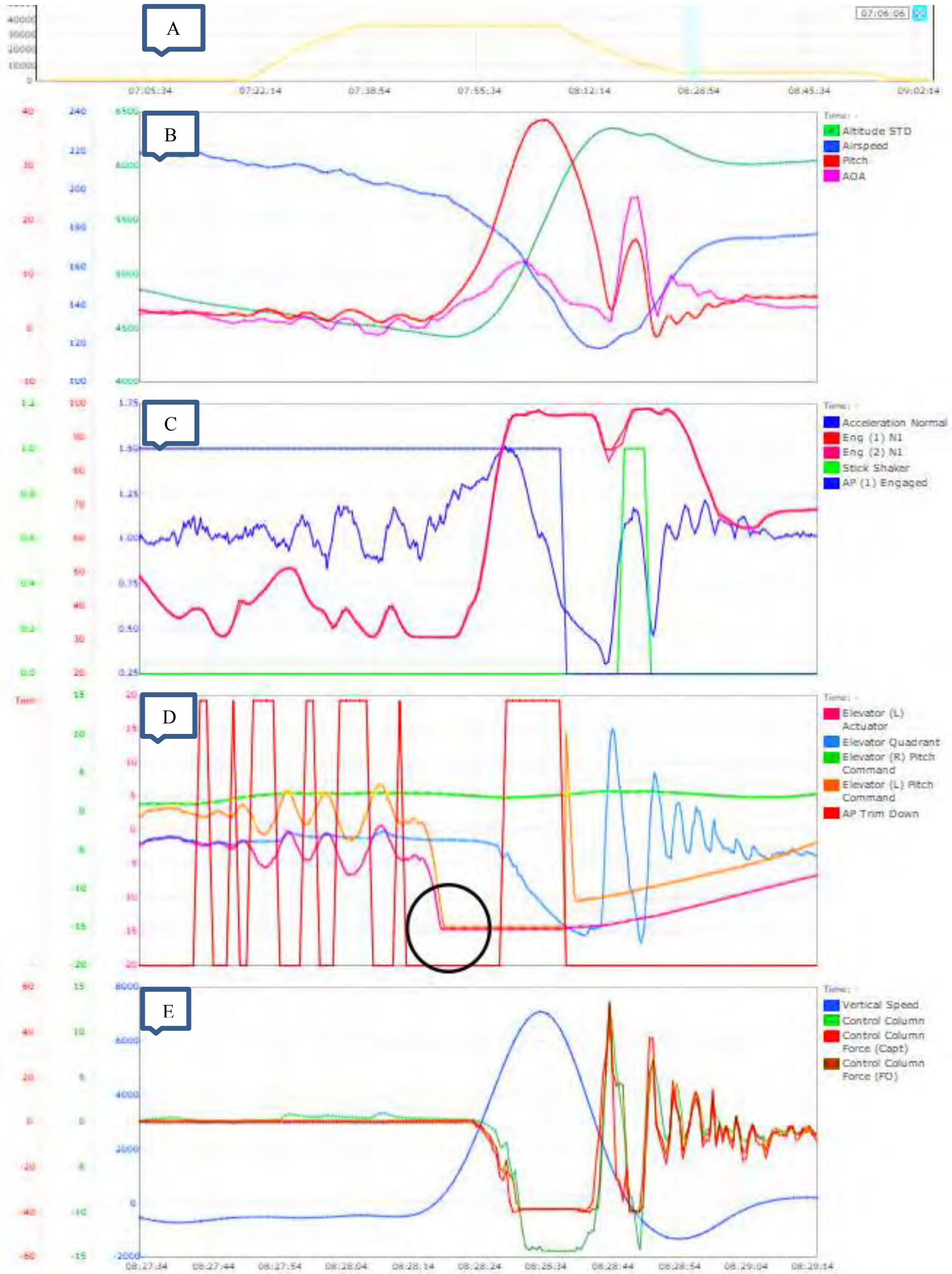

Figure 1: Excerpt from flight data recorder during the incident.

Figure 1A shows aircraft flight profile (the whole flight).
Figure 1B shows altitude, airspeed, pitch and angle of attack.
Figure 1C shows engine thrust, status on stick shaker, status on autopilot and acceleration (G load).
Figure 1D shows black circle marks blockage of the Power Control Units.
Figure 1E shows forces on control column.

1.1.2.5 When the aircraft's nose position passed +12°, both pilots started to push the control column, in an attempt to lower the aircraft's high nose angle. At this time, the aircraft was in clouds (IMC). During the first phase, while the aircraft's nose was unintentionally rising, no attempt was made to disengage the aircraft's autopilot, autothrottle system or manually run the electric stabiliser trim in the nose-down direction. Neither was the engine power reduced. One or more of these measures would have resulted in the aircraft levelling off at an earlier stage. According to the commander's subsequent statement, he believed that the autopilot had disengaged in an early phase when the aircraft's nose started to rise. The aircraft type is designed so that if pilots push or pull the control column with a certain force[3], the autopilot will automatically disengage[4] (see Chapter 1.6.3.13).

1.1.2.6 The maximum nose angle of +38.5° occurred two seconds after the pilots had achieved full force forward on the control column until the mechanical stop. The flight data recorder shows that the pilots used a total force of 174 lb[5]. Only after the aircraft had reached the top and aircraft's nose position passed +35° on its way down, did the pilots manually use the electric trim, which resulted the autopilot to automatically disengage. The aircraft's nose angle rose unintentionally from +1.5° to +38.5° over a period of 20 seconds. At the same time, the airspeed dropped to an alarmingly low speed of 118 kt (CAS). The pilots were eventually able to slowly lower the nose position.

1.1.2.7 Calculations made by Boeing indicate that the elevator was extremely slow in responding. With only 0.2°/second, compared with the normal 50°/second. This indicates a rate of 1:250 compared with the normal response.

1.1.2.8 While control was being regained, when the nose angle passed +10°, the pilots quickly pulled the control column back with a force of approximately 100 lb[6]. This overcorrection caused the aircraft's nose to rise again to + 16°. The angle of attack had then reached about 25° AOA and caused the “Stick Shaker” and stall warning to activate for four seconds.

1.1.2.9 The aircraft climbed 1 928 ft (from the lowest altitude of 4 421 ft AMSL (approximately 3 800 ft above airport elevation) to the maximum altitude of 6 349 ft AMSL) over the course of 24 seconds.

1.1.2.10 Subsequent calculations have shown that the stalling speed, at 1 G wing load, is 121 kt for the configuration in question. The aircraft thus experienced a brief period with airspeed of 3 kt below stall speed. Nevertheless, the aircraft did not stall because the wing load was only 0.30 G while the airspeed was at its lowest[7].

1.1.2.11 After the pilots succeeded in regaining control of the aircraft, they established the aircraft in a holding pattern.

1.1.2.12 The crew on board LN-DYM suspected that a severe temperature inversion might have caused the incident. Upon request from Kittilä TWR, crew thus stated this as the cause of

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[3] More than 25 lb (about 11 kg) when autopilot channel A or B is engaged and more than 50 lb (about 22 kg) when both autopilot channel A and B are engaged, depending that the force is applied for a period of time and system positions.
[4] Disengagement of the autopilot gives a characteristic caution sound.
[5] Approximately 79 kg
[6] Approximately 44 kg
[7] Based on calculations from “Performance Engineers Manual. Boeing issue no 38, NSB, date 06.01.2009 model no 737-800WSFP17CFM56-7B26, section 2 Aerodynamic Data”.

the missed approach. There was then an exchange of information between the crew and the tower regarding the temperature conditions outside the aircraft and on the ground.

1.1.2.13 The aircraft had enough fuel to be able to fly to Rovaniemi as an alternate airport, plus mandatory fuel reserves. After nearly half-an-hour in a holding pattern and after the pilots had verified that the relevant systems functioned as normal, the commander decided to carry out a new approach. The approach and landing at 10:59 hours was uneventful.

1.1.2.14 AIBN has not received information to indicate that any of the passengers have reacted to the aircraft's movements.

1.1.3 Incident notification

1.1.3.1 The commander did not make any remarks of the incident in the aircraft's technical log. Therefore, no assessment was made as to whether LN-DYM should be taken out of operation after the landing in Kittilä, or after the aircraft later returned to Helsinki.

1.1.3.2 The commander has explained to AIBN that, after the landing in Kittilä, he called the airline's Maintenance Control Center (MCC) at Gardermoen via telephone to inform them about the incident and check the need for potential measures. He has told he informed them about the aircraft's autopilot unintentionally making the aircraft climb abruptly and that the pilots had to manually push the control column, in addition to the fact that the aircraft's “stick shaker” had been activated. He informed them that the aircraft had flown through a temperature inversion during approach and that he did not have anything to remark in the aircraft's technical log. The commander has told AIBN that he and the on-call representative at the MCC discussed the different alternatives and decided that the aircraft could continue flying. The first officer agreed with this decision.

1.1.3.3 Two days later, on 28 December 2012, the commander contacted the on-call chief pilot (Director Flight Operations) in Norwegian Air Shuttle and informed him about the incident. The on-call chief pilot did not perceive the incident to be serious, and implemented no special measures vis-à-vis either the aircraft or crew.

1.2 Injuries to persons

Table 1: Personal injuries

Injuries	Crew	Passengers	Others
Fatal			
Serious			
Minor			
None	6	173[8]	

1.3 Damage to aircraft

None.

1.4 Other damage

None.

[8] Including 3 infants

1.5 Personnel information

1.5.1 Commander

1.5.1.1 Commander: Male, 37 years old

Licence: ATPL (A) (JAR-FCL) valid until 29 April 2017

Privileges: B737-300-900 valid until 30 April 2013

IR ME/MP valid until 30 April 2013

TRI (MPA) valid until 28 February 2013

Language test: English valid until 31 March 2015

Medical certificate: Class 1 without restrictions and valid until 12 June 2013

OPC/PC: Valid until 30 April 2013

1.5.1.2 The commander completed his pilot training in Estonia and was certified as a pilot in 1993. During his first years he e.g. flew Antonov 28. In 1998, he was hired by Estonian Air, where he initially flew Fokker 50 and, since 2002, Boeing 737 Classic as first officer and as commander from 2007. During the period from 2009 to early 2011, he flew as commander on Boeing 737 for an Estonian charter company.

1.5.1.3 In March 2011, he started a course to fly as commander for Norwegian Air Shuttle on Boeing 737-800 NG (Next Generation). The course consisted of three weeks in the training department, and then simulator training as well as route training in a total of 40 sectors with final exams.

1.5.1.4 The commander is employed by an agency that leases pilots to e.g. Norwegian. In Norwegian Air Shuttle, he has been stationed at the company's base in Helsinki and has exclusively flown Boeing 737-800 NG.

Table 2: Commander's flying hours

Flying hours	All types	Relevant type
Last 24 hours	2	2
Last 3 days	5	5
Last 30 days	Not stated	Not stated
Last 90 days	Not stated	Not stated
Total	8 880	3 500

1.5.1.5 During his free periods, the commander lived in Tallinn, whereas during work periods he lived near Vantaa airport in Helsinki. The day before the incident he was on standby and spent this time in Helsinki.

1.5.1.6 The commander has stated that he felt rested on the day of the incident and had eaten breakfast.

1.5.1.7 On the day of the incident, he drove from his residence in Helsinki. Check-in time was 07:35 hours and planned departure at 08:47 hours.

1.5.1.8 This was the first time the commander flew with the first officer. The first officer on the flight in question was also a commander in the company. The commander was experienced in flying with other commanders and did not consider this as a problem.

1.5.1.9 The commander had flown to Kittilä about ten times before. He has stated that flying to Kittilä was not significantly different from flying to other airports, where the weather can also change quickly.

1.5.2 First officer

1.5.2.1 First officer: Male, 45 years old

Licence: ATPL (A) (JAR-FCL) valid until 14 March 2017

Privileges: B737 (300-900), valid until 28 February 2013

IR ME/MP valid until 28 February 2013

Language test: English with no expiration

Medical certificate: Class 1 without restrictions and valid until 3 March 2013

OPC/PC: Valid until 28 February 2013

1.5.2.2 The first officer was certified as a commercial pilot in 1993, following training in the US and Denmark. During the period 1997-2008, he flew for Maersk Air and Sterling on Boeing 737 and Bombardier (Canadair) CRJ. He also flew for Air India in 2009-2010 and Astraeus in 2010-2011. Since 2008, he has flown as a commander on Boeing 737.

1.5.2.3 In January 2012, he started flying as a commander on Boeing 737 for Norwegian Air Shuttle. The first officer has been stationed at the company's base in Helsinki and has exclusively flown Boeing 737-800 NG.

Table 3: First officer's flying hours

Flying hours	All types	Relevant type
Last 24 hours	2	2
Last 3 days	2	2
Last 30 days	167	167
Last 90 days	574	574
Total	11 500	7 803

1.6 Aircraft information

Figure 2: Boeing 737-800 NG, LN-DYM. Photo: Private

1.6.1 LN-DYM data

Aircraft type:	Boeing 737-800 Next Generation (B737-8JP)
Serial number:	39005
Production year:	2011
Total number of flight hours:	6 468:30
Total number of cycles:	3 788
Last A1 & C inspection:	25 December 2012
Last C and winter inspection:	7 January 2012
Main LH Elevator Power Control Unit (PCU):	P/N: 251A2160-2/, S/N: 14443 (not replaced since the aircraft was delivered from Boeing)
Main RH Elevator Power Control Unit (PCU):	P/N: 251A2160-2/, S/N: 14475 (not replaced since the aircraft was delivered from Boeing)

1.6.2 Centre of gravity and cargo

1.6.2.1 Estimated mass upon landing: 64 053 kg

Maximum permitted mass upon landing: 66 360 kg

Estimated centre of gravity upon landing: 24.4% MAC

The aircraft's balance was within the permitted limit values.

1.6.2.2 AIBN has made calculations to ascertain whether cargo shifting backwards in the cargo holds may have caused the incident. The calculations show that, if all cargo in cargo hold no. 1 had shifted to no. 2, and all cargo from cargo hold no. 3 shifted to cargo hold no. 4 at the same time, the centre of gravity would still have been within the permitted limitations.

1.6.3 Elevator system – Power Control Units (PCUs)

1.6.3.1 The following will describe the aircraft's elevator system with associated Power Control Units (PCUs):

1.6.3.2 The elevator system is located in the Tail Cone Compartment. There is a mechanical cable transfer from the control columns at the flight deck and back to the Tail Cone Compartment (see Figure 4). The cables are connected to transfer arms that twist the lower "Elevator Input Torque Tube". From there, force is transferred via two compressible rods "Input Pogo's" to the four Input cranks on the aircraft's two PCUs (see Figure 4 and Figure 6).

1.6.3.3 Boeing 737 Classic (100-500 series) is equipped with two elevator PCUs. Each PCU has an Input crank. Boeing 737 NG Next Generation (600-900 series) also has two elevator PCUs. In order to increase redundancy, Boeing has chosen to equip each of the two PCUs with two Input cranks (primary and secondary) (Primary Input crank and Secondary Input crank), i.e. a total of four Input cranks.

1.6.3.4 The PCUs are controlled by a 3 000-psi hydraulic system pressure. The PCU's function as actuators and rotate the "Elevator Output Torque Tube", which in turn directly moves the elevator up and down.

1.6.3.5 The elevator is located on the trailing edge of the horizontal stabiliser. The aircraft is trimmed by changing the mounting angle of the horizontal stabiliser. The trimming is electrical and is controlled automatically or via the trim switches on the control column at the flight deck. The horizontal stabiliser makes up a relatively large surface that largely affects the aircraft's aerodynamic forces around the lateral axis (pitch) (see Figure 3).

1.6.3.6 With the autopilot engaged in approach mode, the Flight Control Computer (FCC) will follow the glideslope beam with pitch commands to the elevator. If elevator PCU's does not respond, the Flight Control Computer will apply command to change horizontal stabilizer angle in order to have the airplane to maintain glideslope.

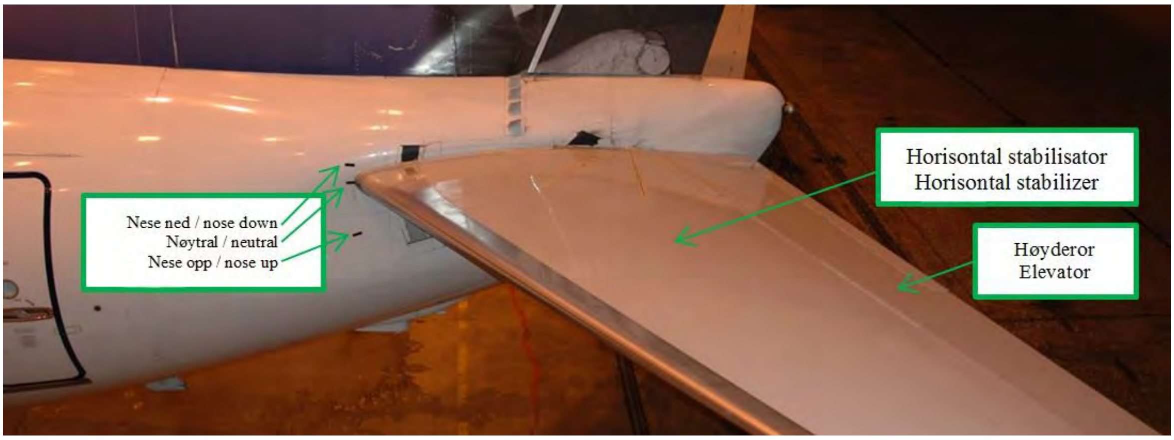

Figure 3: Shows the size ratio between the horizontal stabiliser and the elevator, as well as the range of motion for the horizontal stabiliser. Photo: AIBN

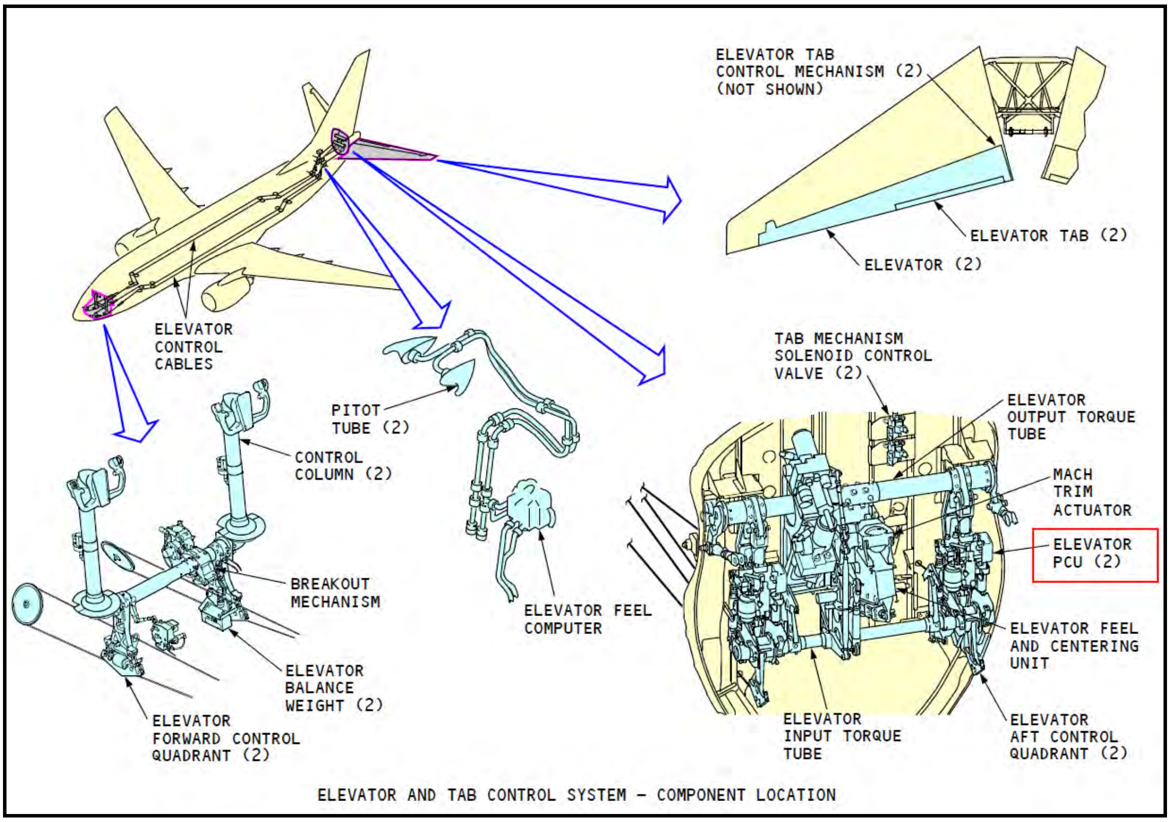

Figure 4: Illustration drawing of the elevator system and component location. Source: - Boeing Proprietary Information. Copyright © Boeing. Reprinted with permission of the Boeing Company

1.6.3.7 The aircraft type's two elevator PCUs are identical. Viewed from the direction of travel, the Primary Input crank on the left PCU and Secondary Input crank on the right PCU are located on the outside toward the fuselage (see Figure 4). The minimum distance from the fuselage opening to the outer Input crank on a PCU is approximately 18 cm (7.9 inches) and the equivalent distance to the inner Input crank is approximately 21 cm (8.3 inches).

1.6.3.8 As is evident from Figure 8, the Secondary Input cranks on the PCUs have a cover that partially enclosed the Input cranks, while the Primary Input cranks have no protective cover. The cover encloses the Input crank toward the back, but has an opening in the aircraft's direction of travel.

1.6.3.9 In AIBN's understanding, the PCUs are equipped with a cover because the same type of PCU is also used to control the ailerons on Boeing 737. The two aileron PCUs are installed in the wheel well with the input cranks horizontal and are therefore more exposed to foreign objects. In order to help prevent any foreign objects from falling down and blocking the Input cranks on the aileron PCUs, they are equipped with a cover over the top Input crank. See Figure 5.

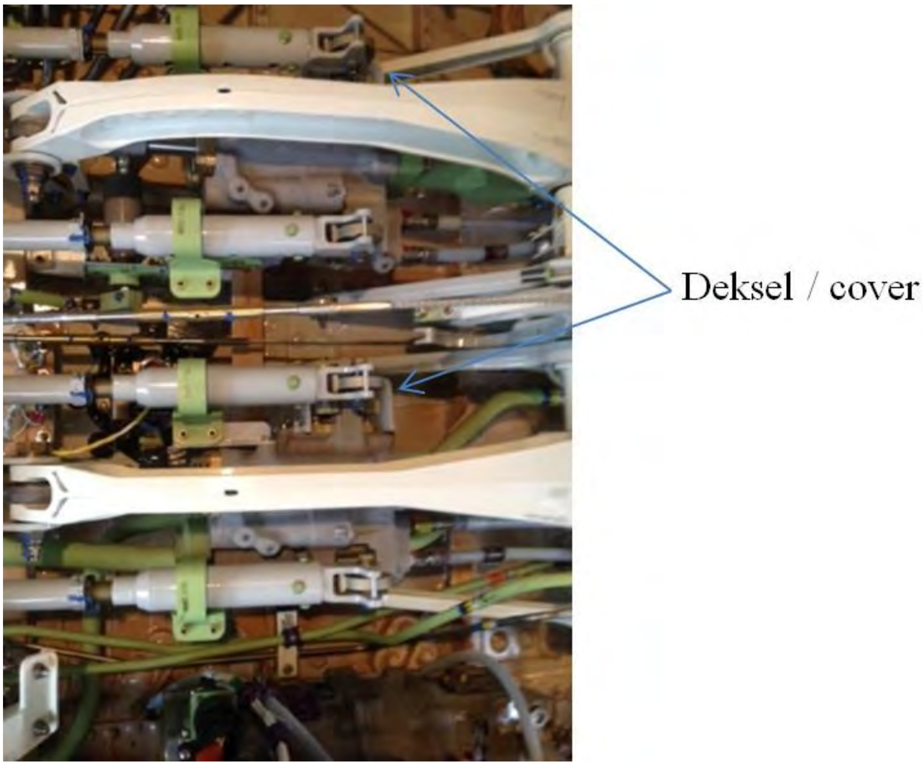

Figure 5: Photo from a Boeing 737-800 wheel well taken in the aircraft's direction of travel. The photo shows that each PCU have a cover over the Secondary Input crank. Photo: AIBN

1.6.3.10 At the lowest point in the Tail Cone Compartment, there is a drainage hole with a diameter of approximately 10 mm in order to drain any fluid that enters the compartment.

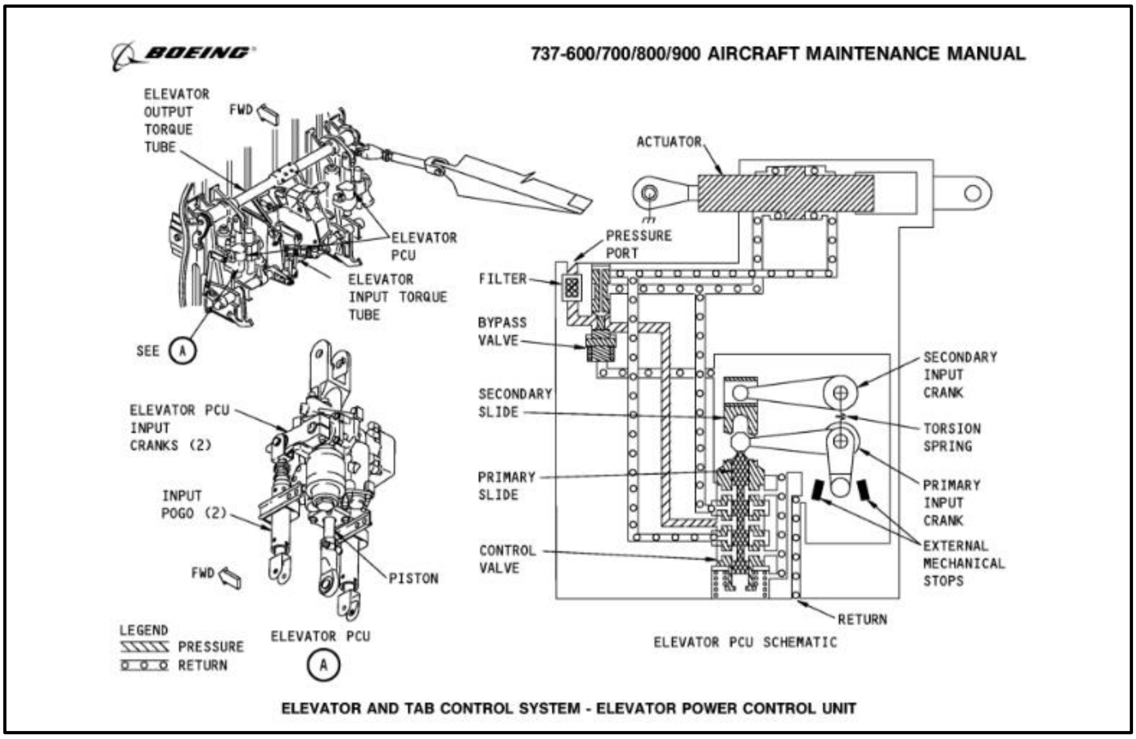

Figure 6: Shows the schematic structure of an elevator PCU. Source: - Boeing Proprietary Information. Copyright © Boeing. Reprinted with permission of the Boeing Company

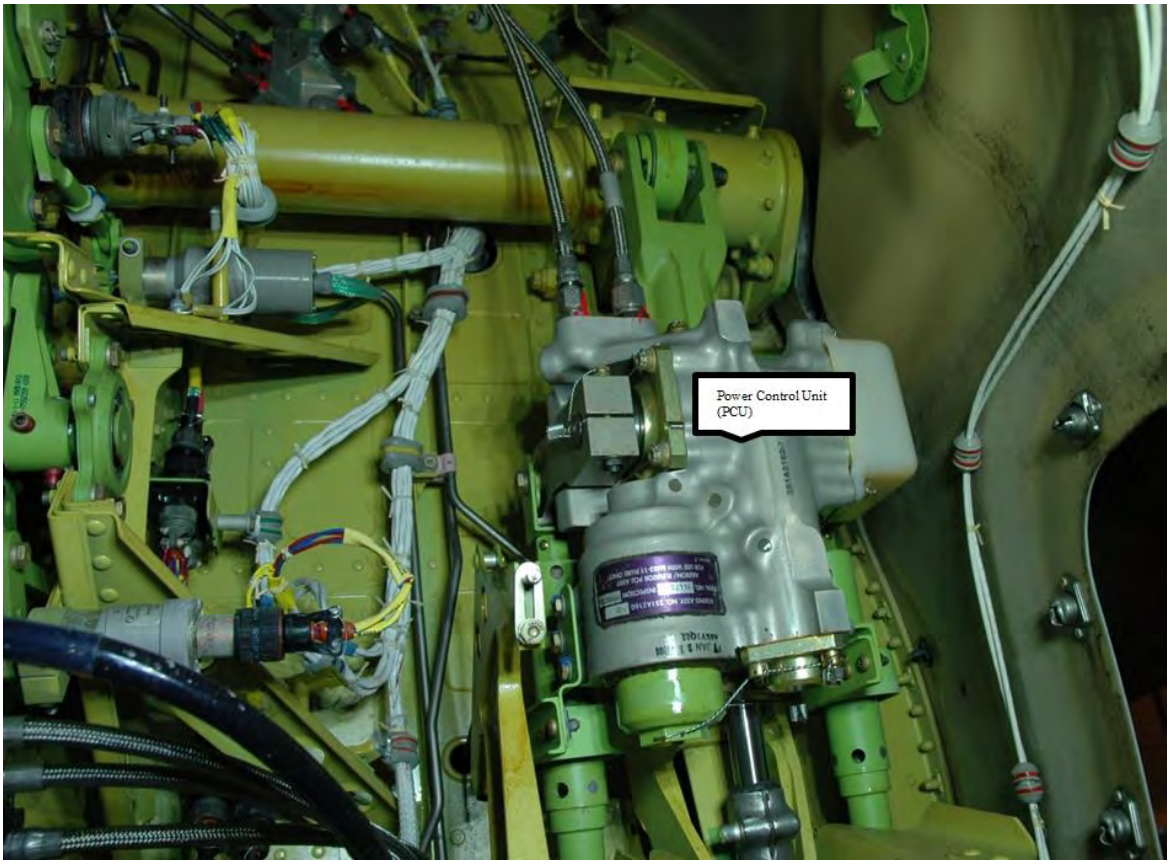

Figure 7: Photo taken inside the Tail Cone Compartment which shows the back of the right PCU on LN-DYM (31 January 2013). Photo: AIBN

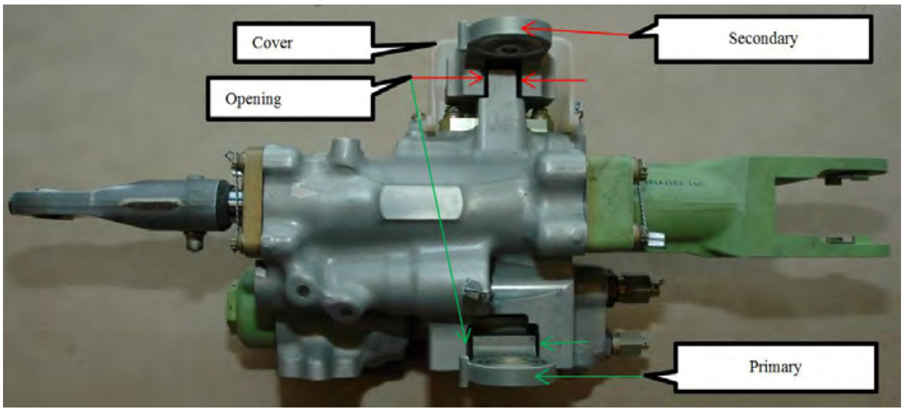

Figure 8: Shows the front of a PCU. Note the narrow gap ("opening") where a foreign object/ice could block movement of the Primary and Secondary Input cranks and thus prevent normal movement on the PCU (actuator) Photo: AIBN

1.6.3.11 AIBN has measured the gap opening on a Power Control Unit to be approximately 1.9 mm (0.075 inch) (marked "opening" in Figure 8). This means that the Input cranks need not move far from the neutral position where the elevator remains in its current position, in order to signal the PCU to move the elevator in the up or down direction. This means that, if a foreign object/ice blocks the gap opening, this will affect normal elevator control.

1.6.3.12 Based on the fact that the flight data recorder proved that blockage of the Power Control Unit had prevented the aircraft's normal elevator function (see Figure 1 and Chapter 1.11.1), AIBN has investigated what may have caused the blockage. These investigations are described in Chapter 1.16.

1.6.3.13 In connection with the draft report, Norwegian has informed about a mismatch in Boeing 737 manuals regarding when the autopilot will automatically disconnect. In Flight Crew Operations Manuals (FCOM) 4 20 date 9. September 2014, it is described that when the autopilot is in approach mode and with both channels engaged, the autopilot shall not disconnect when the control column is pushed or pulled. In the Aircraft Maintenance Manual (AMM) 22-11-00-093 rev55 it is a more general text which does not tell whether or not this is valid when one or both autopilot channels is engaged. Norwegian considers the text in the AMM as correct.

1.7 Meteorological information

1.7.1 Wind directions varied during the period 23-26 December 2012, while LN-DYM was parked outdoors at Helsinki airport Vantaa, mainly from the east and wind speeds were up to 15 kt. Temperatures varied between -7 °C and -19 °C, and there were snow showers.

1.7.2 METAR for Helsinki airport Vantaa on 26 December:

During de-icing: EFHK 0650Z 28007KT CAVOK M17/M19 Q0998 NOSIG
During departure: EFHK 0720Z 28003KT CAVOK M17/M20 Q0998 NOSIG

1.7.3 NAX5630 flew Helsinki – Kittilä at flight level FL360, equivalent to approximately 36 000 ft. The aircraft's flight recorder registered an outside temperature of between -60 and -65 °C at cruising altitude (see Figure 9).

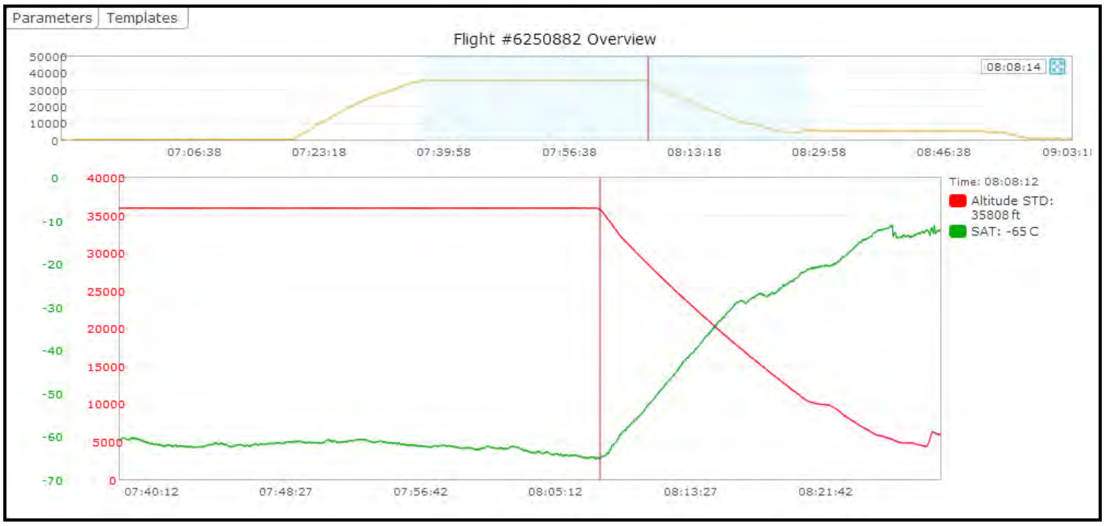

Figure 9: Shows outside temperature (SAT) from when the aircraft was established at cruising altitude until just after the incident in Kittilä. Source: AIBN (data acquired from the aircraft's flight recorder)

1.7.4 TAF Kittilä airport on 26 December:

EFKT 0527Z 06/15 03002KT 9999 FEW007 TEMPO 06/09 6000 IC BECMG 12/14 BKN008=

1.7.5 METAR Kittilä airport on 26 December:

First approach: EFKT 0820Z 00000KT 9999 OVC025 M21/M24 Q0992 34490154
Second approach: EFKT 0920Z 00000KT 9999 OVC024 M20/M22 Q0993 34490154

1.7.6 The aircraft was in clouds (IMC) while the unintentional climb took place. Cloud cover over Kittilä was from just above 5 000 ft and down to about 2 400 ft.

1.7.7 See Appendix E for additional meteorological information.

1.8 Aids to navigation

1.8.1 ILS/DME to runway 34 with frequency 111.900 MHz and identification “KT”.

1.8.2 Kittilä also has an LLZ/DME approach to runway 16 on the same frequency, 111.900 MHz, but with identification “HOU”.

1.8.3 NAX5630 used the ILS/DME 34 approach to Kittilä airport.

1.8.4 No irregularities were reported as regards to the aids for approach.

1.9 Communications

The audio recording between NAX5630 and Kittilä Tower on frequency 118.950 MHz shows that the communication was normal and of good quality.

1.10 Aerodrome information

1.10.1 The airport's reference elevation is 645 ft above sea level.

1.10.2 Upon request from AIBN, the Finnish Safety Investigation Authority has stated that there is a tower with radio and TV transmitters approximately 30 km southwest of Kittilä airport. AIBN is familiar with instances involving disturbances in various aviation systems when aircraft pass in the immediate vicinity of very powerful HF radio stations. Because the transmitters were far away, and given their frequencies and transmitter power, they cannot have contributed to the incident in question. This will therefore not be discussed further in the report.

1.10.3 Air Traffic Control service's radar data

1.10.3.1 There is radar coverage in the area around Kittilä airport and NAX5630's approach was registered on radar.

1.11 Flight recorders

LN-DYM was, in accordance with regulatory requirements, equipped with both a Digital Flight Data Recorder (DFDR) and Cockpit Voice Recorder (CVR).

1.11.1 Analysis of flight data recorder

1.11.1.1 Data from the DFDR have been of crucial importance for the investigation.

1.11.1.2 AIBN, along with representatives from the Flight Safety department in Norwegian Air Shuttle, conducted analyses of the flight data from the flight to Kittilä at Flight Data Services in the UK in January 2013.

1.11.1.3 In parallel with the above, AIBN supplied the aircraft manufacturer Boeing with data from the aircraft's flight recorder and other relevant information. Based on this, Boeing provided a preliminary analysis of the flight data on 31 January 2013, which showed possible blockage of one of the aircraft's two elevator Power Control Units (PCUs).

1.11.1.4 The above-mentioned analysis was the basis for Boeing's recommendation to Norwegian Air Shuttle to replace both Power Control Units in the elevator system in LN-DYM (see Chapter 1.16.3).

1.11.1.5 Boeing and the NTSB have subsequently conducted additional analyses of the aircraft's flight data for the flight in question to Kittilä, as well as flights during the days leading up to this. In January 2014, AIBN received an analysis from Boeing which indicated that LN-DYM's elevator had been gradually blocked while enroute at cruising altitude. The analysis could only determine that at least three of the input arms had to be blocked to match the flight data.

1.11.1.6 In April 2014, Boeing submitted a so-called “Easy 5 Analysis of Elevator Restriction”. In this extensive analysis, Boeing has assessed all scenarios that may have prevented normal elevator operation. The analysis concludes that the most likely scenario was blockage of either three out of four input cranks or all four input cranks.

1.11.2 Data from the cockpit voice recorder

1.11.2.1 The on-board cockpit voice recorder had a two-hour storage capacity. As the incident was not perceived as serious and LN-DYM continued to operate, the recordings on the cockpit voice recorder was not preserved. This has caused that AIBN has had very limited possibilities to assess the crew resource management (CRM).

1.11.2.2 As regards requirements for preserving recordings on the cockpit voice recorder, reference is made to the authority provisions in:

EASA-OPS 1.085 (f) 10 (ii):

not permit:

(ii) a cockpit voice recorder to be disabled or switched off during flight unless he/she believes that the recorded data, which otherwise would be erased automatically, should be preserved for incident or accident investigation nor permit recorded data to be manually erased during or after flight in the event of an accident or an incident subject to mandatory reporting;

EASA-OPS 1.160 (a) 2:

Preservation, production and use of flight recorder recordings

(a) Preservation of recordings:

2. Unless prior permission has been granted by the Authority, following an incident that is subject to mandatory reporting, the operator of an aeroplane on which a flight recorder is carried shall, to the extent possible, preserve the original recorded data pertaining to that incident, as retained by the recorder for a period of 60 days unless otherwise directed by the investigating authority.

1.11.2.3 Norwegian Air Shuttle's authority-approved Operations Manual includes procedures that reflect the above regulatory requirements in OM A Chapters 1.4.1 and 11.5.

1.11.2.4 AIBN has previously discussed the same issue where recordings on cockpit voice recorders are not available for AIBN. In this connection reference is made to e.g. SL RAP 2003/40 pp. 4-5 and page 14 and safety recommendation SL T 33/2003, as well as SL RAP 2006/08 Chapters 1.11.4-8 and 2.5.7 with associated safety recommendation SL T 13/2006.

1.11.2.5 AIBN refers in this connection to the proposed rule change (Notice of Proposed Amendment 2013-26) from EASA, which e.g. includes requirements related to extended recording time for cockpit voice recorders.

1.12 Wreckage and impact information

Not relevant.

1.13 Medical and pathological information

1.13.1 Medical information not investigated.

1.13.2 Pathological information not relevant.

1.14 Fire

Not relevant.

1.15 Survival aspects

Not relevant.

1.16 Tests and research

1.16.1 Introduction

1.16.1.1 The following investigations have been conducted to reveal what could have prevented normal elevator function on LN-DYM:

- Test flight
- Visual inspection of the Tail Cone Compartment
- Inspection of hydraulic oil and filters
- CT scan of the PCUs
- Laboratory tests of pollutants on the PCUs
- Function test of the PCUs at room temperature and in cold chamber
- Disassembly of the PCUs and check of individual components
- Function test of the Flight Control Computer (FCC)
- Simulated de-icing (spray tests 1, 2, 3, 4, 5)
- Simulations in cold chamber
- Measuring temperature changes in the Tail Cone Compartment

1.16.2 Test flight

On 11 January 2013, a one-hour test flight was conducted with LN-DYM from Gardermoen with the assistant chief pilot as commander. An excerpt from "Boeing 737-800 Customer Demonstration Check Flight Report (CDCFR)" was used. During the test flight, the pilots e.g. verified that the necessary force needed on the control column in order to achieve automatic disengagement of the autopilot functioned as normal. Various checks were also conducted on different autopilot modes and the Flight Control Computer. The aircraft functioned normally, and there were no remarks.

1.16.3 Replacement and inspection of Power Control Units (PCUs)

1.16.3.1 On 31 January 2013, Boeing submitted a recommendation to Norwegian Air Shuttle to replace both elevator PCUs on LN-DYM. The recommendation was based on the analysis of flight data that indicated a blockage of one or both PCUs. Norwegian decided to immediately route the aircraft to Gardermoen, where the company has its main technical base. At the time, LN-DYM was enroute from Helsinki to Barcelona.

1.16.3.2 Shortly after LN-DYM had landed and arrived at the airline's hangars at Gardermoen on 31 January 2013, representatives from AIBN, the Civil Aviation Authority - Norway and

Norwegian Air Shuttle conducted a thorough external visual inspection of the elevator and horizontal stabiliser with associated fairings and hinges. No abnormal discoveries were made. An equally thorough internal visual inspection was conducted in the Tail Cone Compartment with special focus on any foreign objects and pollutants on the aircraft's two Power Control Units (PCUs). The associated transmissions between the elevator and horizontal stabiliser were also thoroughly checked. At the time, LN-DYM was only 1 ½ years old, and the relevant components appeared to be clean and without external damage. No abnormal discoveries were made.

1.16.3.3 AIBN was present during removal of the two elevator PCUs and then took both units into custody. The aircraft was taken out of operation for a subsequent period of approximately ten days.

1.16.4 Analysis of hydraulic oil and filters

1.16.4.1 Except from change of filters and refill of hydraulic oil, no maintenance had been necessary on the hydraulic system since LN-DYM was delivered new from factory.

1.16.4.2 AIBN determined that there was a need to investigate samples of the hydraulic oil and filters on LN-DYM. AIBN was present while hydraulic oil samples were taken and hydraulic filters were extracted from both System A and System B. The hydraulic oil and filters were then taken into custody by AIBN. It was immediately ascertained that the hydraulic oil had an abnormal brown/black colour, compared to its normal blue colour. The oil also smelt burnt.

1.16.4.3 AIBN requisitioned the Norwegian Defence Laboratories, Analytical Laboratories, Chemistry and Material Technology (Forsvarets Laboratorietjeneste) to analyse both the hydraulic oil and filters. The analyses showed that the hydraulic oil in systems A and B deviated from the specifications from the hydraulic oil manufacturer, but was within the specifications designated by Boeing for use on Boeing 737. Mineral particles discovered on the primary filters in the hydraulic system would have excluded the oil from being approved if using the specifications from the hydraulic oil manufacturer.

1.16.4.4 Norwegian Air Shuttle later chose to replace all hydraulic oil and associated filters on LN-DYM. The company furthermore, on its own initiative, took samples of hydraulic oil from 10 % of the other aircrafts in its fleet. This was done to ascertain whether the discoveries on LN-DYM also existed on the company's other aircrafts. No equivalent discoveries were made on the other aircrafts.

1.16.5 CT scan of Power Control Units

In order to investigate whether any foreign objects inside the PCUs may have caused a blockage, AIBN, in cooperation with the NTSB, requisitioned an advanced CT scan of both units in the US. The CT scans indicated the presence of a small Foreign Object Debris (FOD) inside one PCU, but no foreign object was later found when the unit was opened. This FOD indication is considered to be an artefact from the CT scan from the machined flat feature of the bypass spool. See also Chapter 1.19 for additional information.

1.16.6 Inspections of the Power Control Units

1.16.6.1 With AIBN present and under its direction, and with assistance from NTSB and Norwegian Air Shuttle, the two relevant PCUs were inspected by the manufacturer in the US.

1.16.6.2 First, residue was collected from the outside of both PCUs in order to prove the presence of de-icing fluid residue. The laboratory tests proved the presence of residue of dehydrated de-icing fluid.

1.16.6.3 Both PCUs were also subject to full functional tests. Function testing also took place in a cold chamber. Both PCUs passed all functional tests and satisfied all associated specifications.

1.16.6.4 Both units were then opened and all components were inspected in detail. Abnormal wear was discovered on certain components in relation to their brief travel time, but this was not deemed to have any connection with the incident in Kittilä and is therefore not discussed further in the report.

1.16.7 Functional test of the Flight Control Computer (FCC)

1.16.7.1 In connection with preparations for replacing the two PCUs on LN-DYM, error codes were discovered in the Flight Control Computer (FCC) in position A during the DFCS BITE TEST (Digital Flight Control System, Built-In Test Equipment). The aircraft type is equipped with two identical Flight Control Computers. The FCC in position A was engaged during the approach to Kittilä. AIBN therefore decided that the relevant FCC would undergo a full functional test.

1.16.7.2 With AIBN present and under its direction, and with assistance from NTSB and Norwegian Air Shuttle, FCC (A) underwent a full functional test by the manufacturer in the US.

1.16.7.3 FCC (A) passed all functional tests that are considered relevant.

1.16.7.4 However, a large number of error codes were discovered in connection with the Mach Trim system. The Mach Trim system automatically switching between using FCC (A) and FCC (B). During the relevant flight to Kittilä, the flight data recorder shows that FCC (B) was controlling the Mach Trim. Mach Trim is only active at speeds above 0.615 Mach.

1.16.7.5 In a meeting with the manufacturer, Rockwell Collins, AIBN requested an expert opinion as to whether the error codes discovered during the functional testing may have affected the course of events in Kittilä. In spite of being promised feedback over the course of April 2013 and repeated inquiries via the NTSB, AIBN has received no response from Rockwell Collins.

1.16.7.6 When the incident in Kittilä occurred, the airspeed was far below 0.615 Mach. AIBN presumes that the identified errors in the Mach Trim system did not affect the Kittilä incident. AIBN has therefore chosen to refrain from requisitioning a full functional test of FCC (B).

1.16.8 AIBN's simulated de-icings

1.16.8.1 As mentioned in Chapter 1.16.3.1, the analysis of flight data indicated blockage of one or both PCUs. A hypothesis thus formed, where the blockage may have been a result of de-icing fluid freezing on the PCU Input cranks and penetrating the narrow gaps as shown in Figure 8. Potential ice in the gaps could prevent the PCUs from functioning as intended.

1.16.8.2 When AIBN met with Boeing experts in the US in March 2013, the representatives could not estimate how much fluid normally could penetrate the Tail Cone Compartment, apart from in minor volumes.

1.16.8.3 In order to clarify whether or not the above was a real issue, AIBN, in consultation with Boeing, the NTSB and Norwegian Air Shuttle, decided to conduct a simulated de-icing on LN-DYM (spray test no.1).

1.16.8.4 AIBN later conducted a total of five simulated de-icings on different Boeing 737 aircraft (spray test no. 1, 2, 3, 4 and 5).

1.16.8.5 During spray test no. 1, de-icing fluid was applied from different directions[9] to the aircraft's horizontal stabiliser and elevator (see Figure 10).

1.16.8.6 The investigation showed that considerable volumes of fluid penetrated the Tail Cone Compartment and that some of the fluid splashed against critical areas on the aircraft's PCU Input cranks (see Figure 11). The result of the spray test no. 1 simulation on LN-DYM was presented to Boeing, the NTSB and Norwegian Air Shuttle.

1.16.8.7 While investigating the Tail Cone Compartment, AIBN found that the clearance around the penetrations on both the left and right sides of the fuselage are wide enough for fluid to enter the compartment. When fluid enters the compartment, it is possible for this fluid to splash on the PCUs as are located below and near the mentioned openings in the fuselage. Since the de-icing fluid is warm, steam from the fluid will condense on cold surfaces.

1.16.8.8 The investigation also showed that, if too much fluid is sprayed on the opening in the fuselage, new fluid will penetrate the compartment faster than it can drain. AIBN does not believe that this is an inherent problem and it is therefore not discussed further in the report.

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[9] 0°, 45°, 90°, 135° and 180°, measured in relation to the aircraft's longitudinal axis.

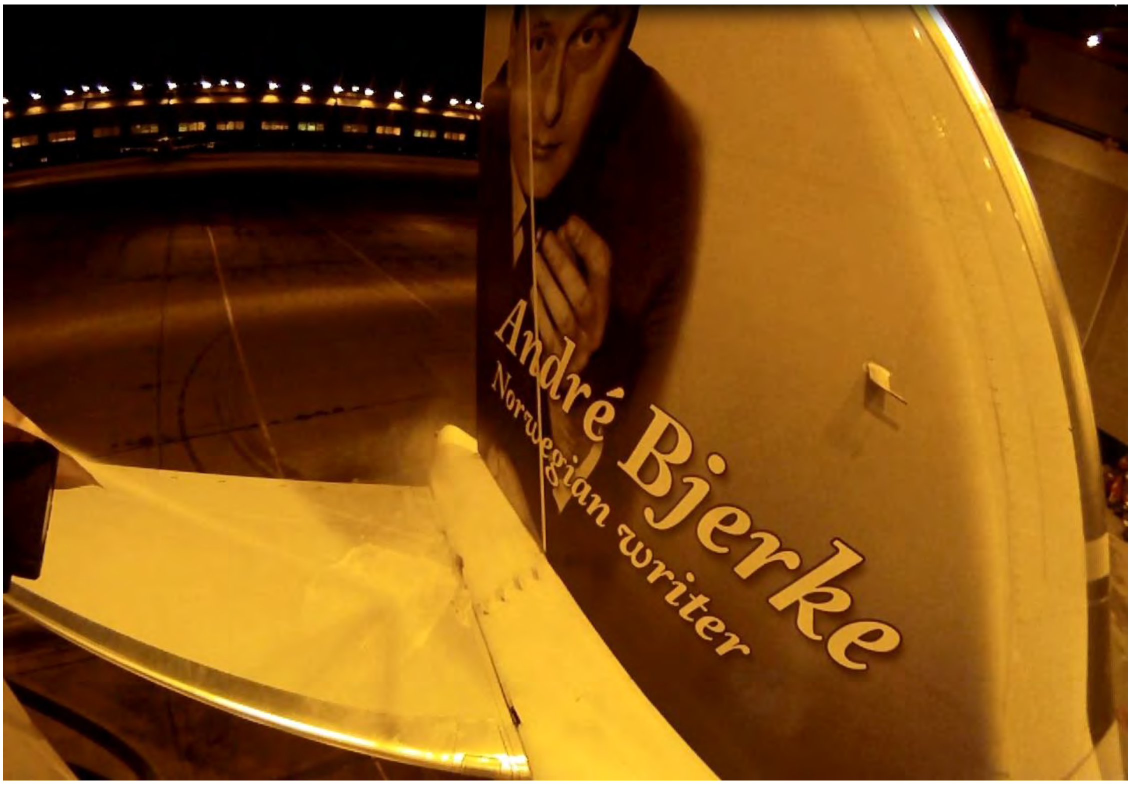

Figure10: "Spray testing" at different marked angles on LN-DYM's horizontal stabiliser and elevator. Photo: AIBN

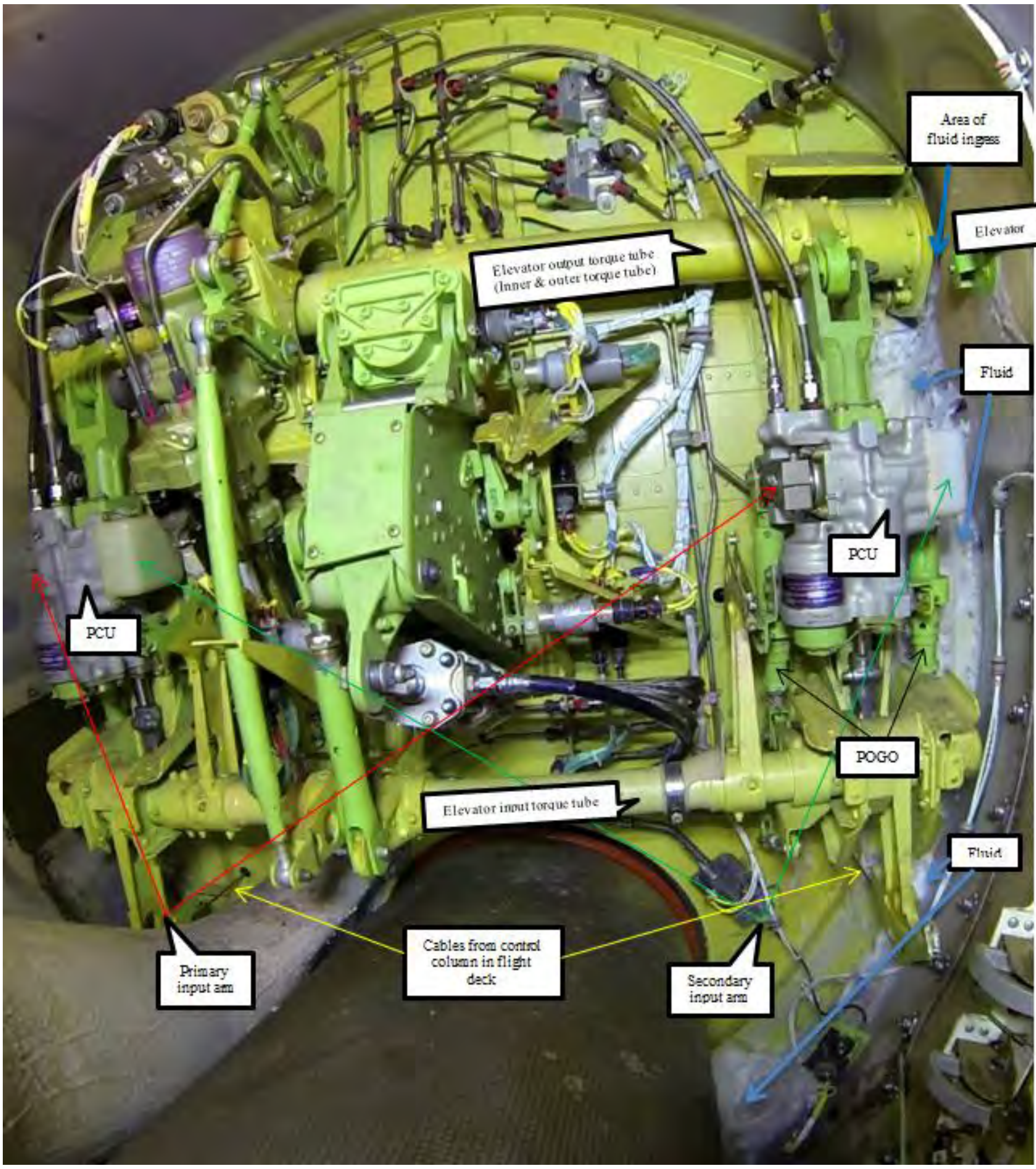

Figure11: Shows fluid penetration and spray potential toward the Input cranks on the PCUs. (Photo taken in the aircraft's direction of travel in connection with simulated de-icing of the aircraft's right side). The pipe at the bottom of the photo is the exhaust pipe from the aircraft's Auxiliary Power Unit (APU). Photo: AIBN

1.16.8.9 Exerpt from video of spray test no. 5 is available at: http://www.aibn.no/Aviation/Published-reports/2015-01-eng

1.16.8.10 As a result of proving substantial fluid penetration on LN-DYM, AIBN decided to conduct an equivalent spray test no. 2 on another Boeing 737-800 NG individual in order to clarify whether the fluid penetration in the relevant compartment was related to the individual (LN-DYM) or aircraft type (Boeing 737-800 NG). The spray test yielded virtually the same result as on LN-DYM, which indicated that the issue is relevant for the entire Boeing 737-800 NG series.

1.16.8.11 On the basis of the above result, AIBN then wanted to clarify whether a comparable issue was also present on a Boeing 737-300 Classic. Spray test no. 3 also showed substantial fluid penetration in the Tail Cone Compartment.

1.16.8.12 The simulations thus indicated that the issue of fluid penetration in the Tail Cone Compartment applies to the entire Boeing 737 fleet (Boeing 737-100-900).

1.16.8.13 AIBN then conducted spray test no. 4 on a Boeing 737-800 NG in order to investigate the impact of the various stabiliser trim positions as regards fluid penetration. The test showed fluid penetration in all positions.

1.16.8.14 As a result of Boeing changed its de-icing procedures and indicated that this should take care of the fluid penetration issue on Boeing 737 (see Chapter 1.18.4.1) AIBN did a new spray test in March 2014. In an e-mail to AIBN, the aircraft manufacturer expected that they no longer saw a need for modifying the aircraft type. AIBN's objective with spray test no. 5 was to study the volume of fluid penetration and how close the fluid penetration came to the Input cranks. AIBN wanted to study the significance of the improvement of Boeing's new procedures on the fluid penetration and whether the exposure of fluid toward the Input cranks was still a real issue.

1.16.8.15 Spray test no. 5 showed that the new procedures regarding the position of the horizontal stabiliser reduced the fluid penetration, but a considerable volume[10] of de-icing fluid still penetrated the compartment.

1.16.8.16 During spray test no. 5, an attempt was also made to measure the change in humidity and temperature when de-icing fluid enters the Tail Cone Compartment. The intention was to analyse whether ice may form on metal surfaces without these surfaces having been directly exposed to de-icing fluid. However, the latter sub-investigation failed from a technical perspective with regard of measuring humidity and temperature change. AIBN has been unable to use the mentioned humidity- and temperature measurements (see Chapter 1.18.3.1 and incident 22. February 2014 as well as Chapter 1.18.3.4). AIBN has, based on video recordings, anyhow been able to conclude a high level of humidity in the Tail Cone Compartment during de-icing.

1.16.8.17 Video recordings from the most important simulated de-icings (the spray tests) have been presented to Boeing, the NTSB and Norwegian Air Shuttle. AIBN is of the opinion that the investigation methods and results have been recognized by those involved.

1.16.8.18 AIBN has not checked whether the issue of de-icing fluid in contact with input cranks on Power Control Units, may also be present on other types of Boeing aircraft or aircrafts from other aircraft manufactures.

1.16.9 Boeing’s simulations in cold chamber

On the basis of AIBN's findings from the simulated de-icings, Boeing chose to conduct its own simulations in a cold chamber on a Boeing 737 Flight Control test rig. By applying fluid to the PCU Input cranks, Boeing was able to produce ice formation and blockage of the Input cranks.

[10] See video in Chapter 1.16.8.9

1.16.10 Measuring temperature changes in the Tail Cone Compartment with the APU in use

AIBN has conducted temperature measurements in the Tail Cone Compartment and the PCUs' Input cranks. This was done to ascertain whether the Auxiliary Power Unit (APU), while in use, contributes to adequately increase the temperature in the compartment and melt any ice that may have settled on the PCUs. The exhaust pipe (see Figure 11) passes through the Tail Cone Compartment and is expected to contribute somewhat toward heating the compartment. The investigation showed that the temperature in the compartment only rose a few degrees, even when the APU had been running for an extended period of time.

1.17 Organizational and management information

1.17.1 Norwegian Air Shuttle

1.17.1.1 Norwegian Air Shuttle was established in 1993 and its main office is at Fornebu. The company has operated Boeing 737 since 2002.

1.17.1.2 The company operates under the brand name Norwegian. As of March 2015, Norwegian actually consists of the following operating companies: Norwegian Air Shuttle (NAS), Norwegian Air Norway (NAN), Norwegian Long Haul[11] and Norwegian Air International Limited (NAI). Norwegian operates Boeing 737 and Boeing 787. The companies have individual Air Operator Certificates (AOCs) and authority-approved personnel.

1.17.1.3 LN-DYM was operated under Norwegian Air Shuttle's (NAS) Air Operator Certificate (AOC) when the incident in Kittilä occurred. In December 2013, LN-DYM was transferred to Norwegian Air Norway (NAN) and then leased back with crews (wet lease) to Norwegian Air Shuttle (NAS).

1.17.1.4 According to the airline's website, as of December 2014, Norwegian is the second largest airline in Scandinavia, and the third largest budget airline in Europe with a fleet of 100 aircraft. 93 of these are Boeing 737 and seven are Boeing 787. In January 2012, Norwegian signed an agreement with both Boeing and Airbus to purchase 222 aircraft, 100 of which were Boeing 737 MAX8, 22 Boeing 737-800 and 100 Airbus A320neo. This is the largest ever agreement in European aviation, and the third largest agreement Boeing has ever made with an airline. The aircraft will be delivered from 2016. Norwegian also has additional Boeing 787-9s on order and the company's long-haul fleet is planning to operate 17 Boeing 787-9s in 2018.

1.17.2 Norwegian's procedures

1.17.2.1 Norwegian Air Shuttle uses standard procedures and associated checklists issued by Boeing.

1.17.2.2 When the Kittilä incident occurred, the company's procedure was to set Stabiliser Trim to full nose-down position in connection with de-icing. After Boeing changed the procedures so that the horizontal stabiliser trim should then be set to the centre position (see Chapter 1.18.4.1), Norwegian Air Shuttle has changed its procedure.

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[11] As far as AIBN understands pr March 2015, the Norwegian Long Haul AOC is inactive.

1.17.2.3 Boeing has issued a number of procedures that are all relevant as regards handling a situation like the one that occurred during the approach to Kittilä. Below you will find the procedures that AIBN believes to be relevant (see Figure 12 through Figure 16).

1.17.2.4 The procedures were obtained from the Boeing 737 Flight Crew Operations Manual (FCOM). Equivalent procedures are also described in the Boeing 737 Flight Crew Training Manual (FCTM), pages 7.32-7.35.

BOEING 9.1
737 Flight Crew Operations Manual

Runaway Stabilizer

Condition: Uncommanded stabilizer trim movement occurs continuously.

1 Control column. . . . . Hold firmly
2 Autopilot (if engaged) . . . . .Disengage
Do **not** re-engage the autopilot.
Control airplane pitch attitude manually with control column and main electric trim as needed.
3 **If** the runaway **stops**:
■ ■ ■ ■
4 **If** the runaway **continues**:
STAB TRIM CUTOUT switches (both) . . . . CUTOUT
If the runaway **continues**:
Stabilizer trim wheel . . . . Grasp and hold
- -
5 Stabilizer. . . . . Trim manually
6 Anticipate trim requirements.
7 **Checklist Complete Except Deferred Items**

▼ Continued on next page ▼

July 14, 2010 D6-27370-8FZ-NSB 9.1

Figure12: Excerpt from Boeing 737 Flight Crew Operations Manual (FCOM) with procedure: "Runaway Stabiliser".
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9.8 BOEING
737 Flight Crew Operations Manual

Jammed or Restricted Flight Controls

Condition: A flight control is jammed or restricted in roll, pitch, or yaw.

1 Autopilot (if engaged) . . . . .Disengage
2 Autothrottle (if engaged) . . . . .Disengage
3 Verify that the thrust is symmetrical.
4 Overpower the jammed or restricted system. Use maximum force, including a combined effort of both pilots, if needed. A maximum two-pilot effort on the controls will not cause a cable or system failure.
5 Do **not** turn off any flight control switches.
6 Choose one:
◆The failure could be **due** to freezing water **and** conditions **allow**:
Consider a descent to a warmer temperature and attempt to overpower the jammed or restricted system again.
►►Go to step 7
◆The failure could **not** be due to freezing water **or** conditions do **not** allow:
►►Go to step 7
7 Choose one:
◆Controls are **normal**:
■ ■ ■ ■
◆Controls are **not** normal:
►►Go to step 8
8 Use stabilizer or rudder trim to offload control forces. If electric stabilizer trim is needed, move the Stabilizer Trim Override switch to OVERRIDE.
9 Do not make abrupt thrust changes. Extend or retract speedbrake slowly and smoothly.
10 Limit bank angle to 15°.

Figure13: Excerpt from Boeing 737 Flight Crew Operations Manual (FCOM) with procedure: "Jammed or Restricted Flight Controls".

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BOEING

737 Flight Crew Operations Manual

Maneuvers **Chapter MAN**

Non-Normal Maneuvers **Section 1**

Approach to Stall or Stall Recovery

All recoveries from approach to stall should be done as if an actual stall has occurred.

Immediately do the following at the first indication of stall (buffet or stick shaker).

Note: Do not use flight director commands during the recovery.

Pilot Flying	Pilot Monitoring
• Initiate the recovery: • Hold the control column firmly. • Disconnect autopilot and autothrottle. • Smoothly apply nose down elevator to reduce the angle of attack until buffet or stick shaker stops. Nose down stabilizer trim may be needed.*	• Monitor altitude and airspeed. • Verify all required actions have been done and call out any omissions. • Call out any trend toward terrain contact.
• Continue the recovery: • Roll in the shortest direction to wings level if needed.** • Advance thrust levers as needed. • Retract the speedbrakes. • Do not change gear or flap configuration, except • During liftoff, if flaps are up, call for flaps 1.	• Monitor altitude and airspeed. • Verify all required actions have been done and call out any omissions. • Call out any trend toward terrain contact. • Set the FLAP lever as directed.
• Complete the recovery: • Check airspeed and adjust thrust as needed. • Establish pitch attitude. • Return to the desired flight path. • Re-engage the autopilot and autothrottle if desired.	• Monitor altitude and airspeed. • Verify all required actions have been done and call out any omissions. • Call out any trend toward terrain contact.

WARNING: *If the control column does not provide the needed response, stabilizer trim may be necessary. Excessive use of pitch trim may aggravate the condition, or may result in loss of control or in high structural loads.

WARNING: ** Excessive use of pitch trim or rudder may aggravate the condition, or may result in loss of control or in high structural loads.

Figure14: Excerpt from Boeing 737 Flight Crew Operations Manual (FCOM) with procedure: "Approach to Stall or Stall Recovery".
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Maneuvers -
Non-Normal Maneuvers

BOEING

737 Flight Crew Operations Manual

Upset Recovery

An upset can generally be defined as unintentionally exceeding the following conditions:

- Pitch attitude greater than 25 degrees nose up, or
- Pitch attitude greater than 10 degrees nose down, or
- Bank angle greater than 45 degrees, or
- Within above parameters but flying at airspeeds inappropriate for the conditions.

The following techniques represent a logical progression for recovering the airplane. The sequence of actions is for guidance only and represents a series of options to be considered and used depending on the situation. Not all actions may be necessary once recovery is under way. If needed, use pitch trim sparingly. Careful use of rudder to aid roll control should be considered only if roll control is ineffective and the airplane is not stalled.

These techniques assume that the airplane is not stalled. A stalled condition can exist at any attitude and may be recognized by continuous stick shaker activation accompanied by one or more of the following:

- Buffeting which could be heavy at times
- Lack of pitch authority and/or roll control
- Inability to arrest descent rate.

If the airplane is stalled, recovery from the stall must be accomplished first by applying and maintaining nose down elevator until stall recovery is complete and stick shaker activation ceases.

Figure15: Excerpt from Boeing 737 Flight Crew Operations Manual (FCOM) with procedure: "Upset Recovery".
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Maneuvers -
Non-Normal Maneuvers

BOEING

737 Flight Crew Operations Manual

The following techniques represent a logical progression for recovering the airplane. The sequence of actions is for guidance only and represents a series of options to be considered and used depending on the situation. Not all actions may be necessary once recovery is under way. If needed, use pitch trim sparingly. Careful use of rudder to aid roll control should be considered only if roll control is ineffective and the airplane is not stalled.

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- Buffeting which could be heavy at times
- Lack of pitch authority and/or roll control
- Inability to arrest descent rate.

If the airplane is stalled, recovery from the stall must be accomplished first by applying and maintaining nose down elevator until stall recovery is complete and stick shaker activation ceases.

Nose High Recovery

Pilot Flying	Pilot Monitoring
• Recognize and confirm the situation	
• Disconnect autopilot and autothrottle • Apply as much as full nose-down elevator • * Apply appropriate nose down stabilizer trim • Reduce thrust • * Roll (adjust bank angle) to obtain a nose down pitch rate • Complete the recovery: - When approaching the horizon, roll to wings level - Check airspeed and adjust thrust - Establish pitch attitude.	• Call out attitude, airspeed and altitude throughout the recovery • Verify all required actions have been completed and call out any omissions.

Figure16: Excerpt from Boeing 737 Flight Crew Operations Manual (FCOM) with procedure: "Nose High Recovery".
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1.17.2.5 Excerpt from Norwegian OM-B when Kittilä occurred:

1.18.18 Guarding of Flight Controls-Company Procedure

Flight deck seats must be adjusted in accordance with FCOM Section 02. Below 5 000 ft both flight crew members must guard the rudder pedals and PF must guard* the control column.*

**Guarding means to have hands/feet in the close vicinity of the controls with the seat and pedals adjusted properly.*

1.17.2.6 Excerpt from Norwegian OM-B as of June 2014:

PF shall always be able to take control of rudder and control column if AP disengages. Flight deck seats must be adjusted in accordance with FCOM Section 02. Below 5 000 ft both flight crew members must guard the rudder pedals and PF guard* the control column.*

**Guarding means to have hands/feet in the close vicinity of the controls with the seat and pedals adjusted properly.*

1.17.3 Pilot training in Norwegian

1.17.3.1 In a meeting with Norwegian Air Shuttle and Norwegian Air Norway, AIBN acquired information about their pilot training. As a result of significant expansion, Norwegian e.g. has required many new pilots. Both new employees and contracted pilots have various background, nationalities and culture. Training and standardisation of pilots is therefore challenging.

1.17.3.2 AIBN has acquired information from Norwegian Air Shuttle and Norwegian Air Norway concerning the content of their authority-approved training program. Of particular interest are the measures implemented prior to and following the Kittilä incident as regards pilot training in the following procedures:

"Runaway Stabiliser"

"Jammed or Restricted Flight Controls"

"Approach to Stall or Stall Recovery"

"Upset Recovery"

"Nose High Recovery"

"Guarding of Flight Controls"

1.17.3.3 Norwegian conducts three simulator training sessions per year with all the company's pilots. Every 6 months they review the Operator Proficiency Check (OPC) and Recurrent compulsory by the Authorities. In addition the company has also chosen to conduct Additional Training every 12 months.

1.17.3.4 The simulator training every six months with OPC/Recurrent mainly consists of training exercises stipulated in the pan-European regulations. In connection with the Additional Training as Norwegian has chosen to provide in addition to the authority mandated minimum requirements, the company is free to select topics. The topics are chosen from international and national incidents the company believes can be used to gain knowledge.

1.17.3.5 During the 2011-2012 additional training, Norwegian Air Shuttle had chosen to train in scenarios from the Turkish Airlines accident, where the pilots lost control of a Boeing 737-800 during its approach to Amsterdam. The factors in this connection were loss of control at low altitude, aborted approach and low airspeed, unusual attitude and the need for using the elevator trim at high engine power or reduced engine power. The commander during the incident in question with LN-DYM had undergone the mentioned simulator training about six months before the incident in Kittilä.

1.17.3.6 In the spring of 2012, Norwegian used learning from the Air France accident where an Airbus 330 stalled at high altitude. During the annual simulator training for the period from September 2012 to September 2013, they had selected topics such as: High Altitude, Buffet and Stall Recovery at High Altitude. The focus was thus on Upset Recovery from high altitude and was based on documentation in the Flight Crew Training Manual (FCTM), Flight Crew Operational Manual (FCOM) and Quick Reference Handbook (QRH).

1.17.3.7 In June 2012, Boeing issued a Flight Operations Technical Bulletin (FOTB) relating to Upset Recovery. It is worth noting that the content of the FOTB was not news, but rather a reminder of what has been in the FCTM and Quick Reference Handbook (QRH) for quite some time. The bulletin applies to most models of Boeing 737, 747, 757, 767, 777 and 787. The bulletin starts by defining an Upset situation, e.g. when an aircraft has a nose angle of more than +25°. In the bulletin, Boeing writes that such a situation could e.g. occur as a result of the aircraft's systems not functioning correctly. Boeing refers to the handbook for the individual aircraft type, but what is common for them all is that the first measure is to disengage the aircraft's autopilot and autothrottle and manually regain control of the aircraft.

1.17.3.8 After the Kittilä incident, Norwegian's training department and operations department chose to focus on Low Altitude Upset Recovery for the simulator period from March 2013 to March 2014. Prior to the mentioned period, the company's chief pilot issued the following Notice to Pilots NG, which reiterates that the first essential measure if the aircraft enters an Upset situation is to: "*Disconnect the autopilot and autothrottle, and recover from the upset manually*".

NOTICE TO PILOTS NG norwegian.no

From:	Chief Pilot B737	Nr:	3/2013
Date:	18.FEBRUAR.2013		
Valid until:	Until Further Notice	Code:	Red **Yellow** Green
Valid NTP	29/09, 22/10, 27/10, 28/10, 31/10, 5/11, 15/11, 19/11, 20/11, 25/11, 1/12, 2/12, 3/12, 4/12, 6/12, 7/12, 8/12, 9/12, 10/12, 11/12, 12/12, 12B/12, 13/12, 14/12, 1/13, 2/13, 3/13		

UPSET RECOVERY

The purpose of this NTP is increase the awareness to pilots in the first basic steps of an upset recovery.

On the 26th of December 2012, a Norwegian flight was flown from Helsinki Airport (EFHK) to Kittila Airport (EFKT) in Finland. As the aircraft intercepted the glideslope it pitched up and nearly stalled as the pilots regained controlled of the aircraft. Both Norwegian and the Norwegian Accident Investigation Board (Statens Havarikommisjon) have started an investigation. The reason why the aircraft suddenly and without notice pitched up is still unknown.

Boeing has published a Flight Operation Technical Bulletin number 737-12-2, dated 25th of June 2012, commenting Upset recovery. The intention of the Bulletin is to to provide increased flight crew awareness of the Upset Recovery non-normal maneuver, and the requirement to disconnect automation as the first step. The Bulletin is attached to this NTP for your reading.

An upset situation is an unintentional situation which can be caused by a variety of issues. The Boeing Flight Crew Operational Manual (FCOM), the Quick Referance Handbook (QRH), and the Flight Crew Training Manual (FCTM) give techniques and hints in how an upset recovery should be done. For pilots the essential thing to know is the first steps of action once an upset is recognized and confirmed:

disconnect the autopilot and autothrottle,

and recover from the upset manually.

Figure17: Notice to Pilots NG, dated 18 February 2013. Source: Norwegian.

1.17.3.9 The company has run the Kittilä incident in the simulator and examined the effect of high engine power on the aircraft's nose position, as well as the effect of redusing engine thrust. At full engine power, it is more difficult to regain control, but there is a greater chance of lowering the nose by reducing engine power.

1.17.3.10 The training department in Norwegian has informed AIBN that, of the topics that are relevant to the Kittilä incident, they train their pilots on departures, climbing and descend, as well as approaches without the Flight Director and only based on Raw Data. They also train for unreliable speed gauges in connection with departure and which cause the automatic systems to display error alerts and the aircraft to have a too high nose angle. Correspondingly when flying out of situations with wind shear and which cause the aircraft to have a high nose position.

1.17.3.11 The company has stated that, e.g. in connection with training pilots with limited experience, it has added three days of theory emphasising Jet Upset and High Altitude Unusual Attitude. Norwegian has also told AIBN that, e.g. in connection with Conversion

Training (transferring pilots from one airline to another), they complete 40 sectors, whereas the authorities only require eight sectors.

1.17.3.12 There is a video online titled "Children of the magenta" from 1997. It shows a representative from American Airlines describing basic principles for handling automated aircraft. Norwegian has stated that they have found this video to be very useful in illustrating the importance of teaching pilots to switch to manual control of the aircraft if they need to handle an Upset Recovery situation.

1.17.3.13 There is no new technique for Upset Recovery, and the basic parameters have remained unchanged for many years. As a result of several incidents involving Loss Of Control and increasing automation in the cockpit, the aviation industry is focusing on this issue. Norwegian has stated that it is devoting significant focus to the mentioned areas and that it will continue to work on this.

1.17.4 Norwegian Maintenance Control Center (MCC/MOC)

1.17.4.1 AIBN's investigations have shown that the company's Maintenance Control Center (MCC) did not register any inquiries in its data log after the Kittilä incident, and technical personnel on duty on the day in question have explained to AIBN that they cannot remember the inquiry from the commander. Inquiries from pilots[12] to the MCC (later called the Maintenance Operations Center, MOC[13]) take place to a dedicated mobile telephone number. Pilots enquire with MCC/MOC for technical support and advice. When the Kittilä-incident occurred, the company did not record telephone inquiries to MOC.

1.17.4.2 Norwegian has enlightened AIBN that the company has not succeeded to bring clarity to what the commander actually conveyed of the information. In connection with the draft of this report, the company has conveyed that they have implemented measures and that starting from now on all calls to MOC and to Operations Control Center (OCC) are recorded.

1.18 Additional information

1.18.1 Guidelines for Stall and Stick Pusher Training

The European Aviation Safety Agency (EASA) has issued guidelines in Safety Information Bulletin SIB 2013-02, dated 22 January 2013, relating to Stall and Stick Pusher Training.

1.18.2 Certification provisions

1.18.2.1 In connection with safety assessment the following equation is in use:

Consequence x Likelihood = Risk Level

---

[12] With the exception of around Gardermoen, where VHF radio is normally used.

[13] In the autumn of 2013, Norwegian separated its Maintenance Operations Center (MOC) from its maintenance department (Part 145) and moved it from Gardermoen to co-locate with the company's Operation Control Center (OCC) at the main office at Fornebu.

1.18.2.2 FAA definition of consequence[14]:

Catastrophic	Results in multiple fatalities and/or loss of the system
Hazardous	Reduces the capability of the system or the operator ability to cope with adverse conditions to the extent that there would be: Large reduction in safety margin or functional capability Crew physical distress/excessive workload such that operators cannot be relied upon to perform required tasks accurately or completely (1) Serious or fatal injury to small number of occupants of aircraft (except operators) Fatal injury to ground personnel and/or general public
Major	Reduces the capability of the system or the operators to cope with adverse operating condition to the extent that there would be – Significant reduction in safety margin or functional capability Significant increase in operator workload Conditions impairing operator efficiency or creating significant discomfort Physical distress to occupants of aircraft (except operator) including injuries Major occupational illness and/or major environmental damage, and/or major property damage
Minor	Does not significantly reduce system safety. Actions required by operators are well within their capabilities. Include Slight reduction in safety margin or functional capabilities Slight increase in workload such as routine flight plan changes Some physical discomfort to occupants or aircraft (except operators) Minor occupational illness and/or minor environmental damage, and/or minor property damage
No Safety Effect	Has no effect on safety

1.18.2.3 FAA definition of likelihood:

Probable	Qualitative: Anticipated to occur one or more times during the entire system/operational life of an item. Quantitative: Probability of occurrence per operational hour is greater that 1 x 10-5
Remote	Qualitative: Unlikely to occur to each item during its total life. May occur several time in the life of an entire system or fleet. Quantitative: Probability of occurrence per operational hour is less than 1 x 10-5, but greater than 1 x 10-7

[14] FAA System Safety Handbook, Chapter 3: Principles of System Safety (December 30, 2000), Acquisition Management System (AMS)

Extremely Remote	Qualitative: Not anticipated to occur to each item during its total life. May occur a few times in the life of an entire system or fleet. Quantitative: Probability of occurrence per operational hour is less than 1 x 10-7, but greater than 1 x 10-9
Extremely Improbable	Qualitative: So unlikely that it is not anticipated to occur during the entire operational life of an entire system or fleet. Quantitative: Probability of occurrence per operational hour is less than 1 x 10-9

1.18.2.4 The Risk Acceptability Matrix in Figure 18 shows that the assessment of risk is made by combining the severity of consequence with the likelihood of occurrence.

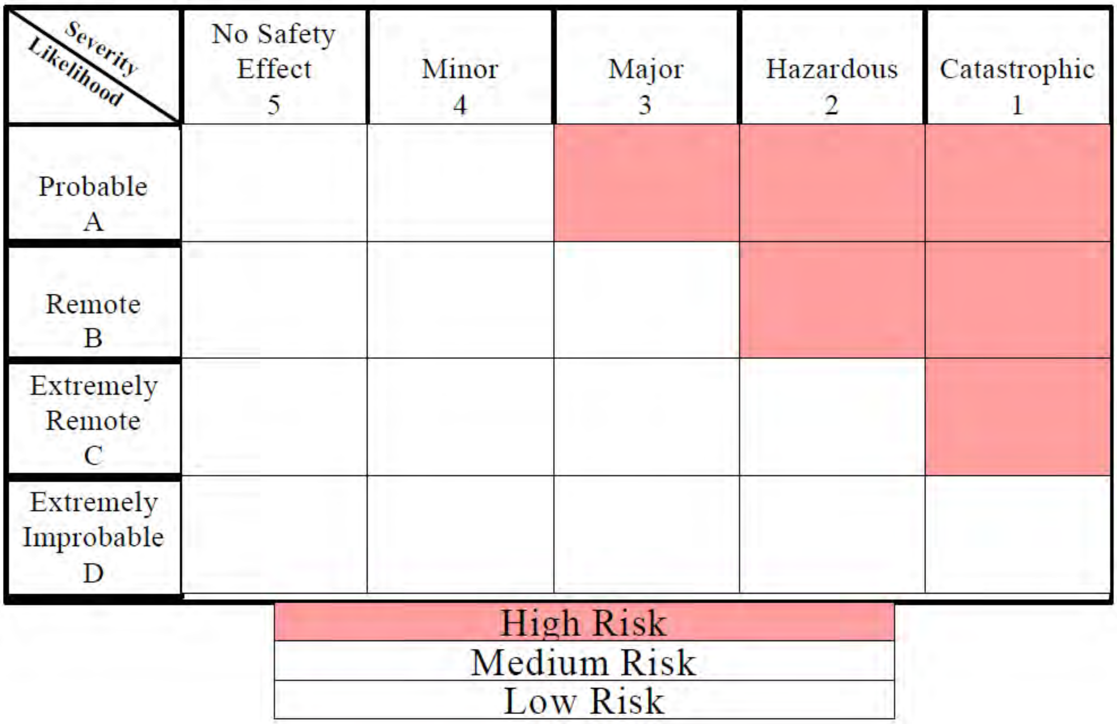

Figure 18: Risk Acceptability Matrix. Source: FAA System Safety Handbook, s. 3-9

1.18.2.5 The following risk acceptance criteria are used:

- **High risk** - Unacceptable. Tracking in the FAA Hazard Tracking System is required until the risk is reduced and accepted.
- **Medium risk** – Acceptable with review by the appropriate management authority. Tracking in the FAA Hazard Tracking System is required until the risk is accepted.
- **Low risk** – Low risk is acceptable without review. No further tracking of the hazard is required.

1.18.2.6 Boeing has informed AIBN that they consider the consequence of a blocked elevator system may be “Catastrophic” (ref. above definitions).

1.18.2.7 The AIBN does not have the overview of the number of occurences with blocked or partly blocked elevator system on the Boeing 737 series. Thus, the AIBN can not determine the likelihood for such an incident and is accordingly not able to state any risk level value. However, through this incident and other incidents as mentioned in Chapter 1.18.3.1 it can be established that it may occur.

1.18.2.8 FAR PART 25, AIRWORTHINESS STANDARDS, TRANSPORT CATEGORY AIRPLANES, CONTROL SYSTEMS

§ 25.671 General.

(a) *Each control and control system must operate with the ease, smoothness, and positiveness appropriate to its function.*

(b) *Each element of each flight control system must be designed, or distinctively and permanently marked, to minimize the probability of incorrect assembly that could result in the malfunctioning of the system.*

(c) *The airplane must be shown by analysis, tests, or both, to be capable of continued safe flight and landing after any of the following failures or jamming in the flight control system and surfaces (including trim, lift, drag, and feel systems), within the normal flight envelope, without requiring exceptional piloting skill or strength. Probable malfunctions must have only minor effects on control system operation and must be capable of being readily counteracted by the pilot.*

(1) *Any single failure, excluding jamming (for example, disconnection or failure of mechanical elements, or structural failure of hydraulic components, such as actuators, control spool housing, and valves).*

(2) *Any combination of failures not shown to be extremely improbable, excluding jamming (for example, dual electrical or hydraulic system failures, or any single failure in combination with any probable hydraulic or electrical failure).*

(3) *Any jam in a control position normally encountered during takeoff, climb, cruise, normal turns, descent, and landing unless the jam is shown to be extremely improbable, or can be alleviated. A runaway of a flight control to an adverse position and jam must be accounted for if such runaway and subsequent jamming is not extremely improbable.*

1.18.2.9 European Aviation Safety Agency (EASA), Certification Specifications, for Large Aeroplanes:

CS-25, Amendment 3, 19 September 2007

CS 25.671 General

(a) Each control and control system must operate with the ease, smoothness, and positiveness appropriate to its function. (See AMC 25.671 (a).)

(b) Each element of each flight control system must be designed, or distinctively and permanently marked, to minimise the probability of incorrect assembly that could result in the malfunctioning of the system. (See AMC 25.671 (b).)

(c) The aeroplane must be shown by analysis, test, or both, to be capable of continued safe flight and landing after any of the following failures or jamming in the flight control system and surfaces (including trim, lift, drag, and feel systems) within the normal flight envelope, without requiring exceptional piloting skill or

strength. Probable malfunctions must have only minor effects on control system operation and must be capable of being readily counteracted by the pilot.

(1) Any single failure not shown to be extremely improbable, excluding jamming, (for example, disconnection or failure of mechanical elements, or structural failure of hydraulic components, such as actuators, control spool housing, and valves). (See AMC 25.671(c)(1).)

(2) Any combination of failures not shown to be extremely improbable, excluding jamming (for example, dual electrical or hydraulic system failures, or any single failure in combination with any probable hydraulic or electrical failure).

(3) Any jam in a control position normally encountered during take-off, climb, cruise, normal turns, descent and landing unless the jam is shown to be extremely improbable, or can be alleviated. A runaway of a flight control to an adverse position and jam must be accounted for if such runaway and subsequent jamming is not extremely improbable.

(d) The aeroplane must be designed so that it is controllable if all engines fail. Compliance with this requirement may be shown by analysis where that method has been shown to be reliable.

1.18.3 Other incidents

1.18.3.1 *Reported incidents in Norwegian during the period 2011-2014*

Norwegian has registered eight incidents where it was necessary to use greater force on the elevator control column than normal[15]:

- 9 December 2011: Boeing 737-800, LN-NIB after landing at Bardufoss airport.
- 3 January 2012: Boeing 737-800, LN-DYN (Oslo - Harstad) approach to Harstad/Narvik Airport Evenes.
- 15 January 2012: Boeing 737-800, LN-DYT (Tromsø - Oslo) approach to Oslo Airport Gardermoen.
- 24 January 2012. Boeing 737-800, LN-DYT (Agadir - Oslo) approach to Oslo Airport Gardermoen.
- 18 February 2012: Boeing 737-800, LN-DYL (Salzburg - Stockholm) approach to Stockholm airport Arlanda.
- 22 October 2013: Boeing 737-800, LN-NGI (Oslo - Bodø) approach to Bodø airport.
- 22 February 2014: Boeing 737-800, LN-DYL (Luleå - Stockholm) approach to Stockholm airport Arlanda. The Tail Cone was not de-iced prior to departure (see Chapter 1.18.3.4).
- 23 February 2014: Boeing 737-800, LN-NGO (Oslo - Tromsø) approach to Tromsø Airport Langnes.

[15] Based on pilots reports.

1.18.3.2 Scandinavian Airlines System (SAS) has informed AIBN that it experiences three to four incidents each winter season where it has been necessary to use greater force than normal/expected on the elevator control column. The incidents have usually been in connection with the aircraft undergoing de-icing prior to departure.

1.18.3.3 The common denominators in the above incidents in Norwegian and SAS are that it had been cold and necessary to use approximatly 35-40 lb of force on the elevator control column, which is about 25 lb more force than normal/expected. As mentioned earlier, the pilots used as much as 174 lb of force on the elevator control column when the incident occurred in Kittilä.

1.18.3.4 The Boeing Aerodynamics Stability & Control Accident/Incident Investigation group and Boeing Engineering Flight Controls group concluded in March 2014 that the flight data from the two incidents Norwegian experienced on 22 and 23 February 2014 showed that it had been necessary for the pilots to use greater force on the elevator control column than normal. Boeing is of the opinion that the most likely scenario was that a restriction had occurred on one of the PCU Input cranks. The incidents occurred after Norwegian had introduced the new de-icing procedures from Boeing.

1.18.3.5 *Tailwind Airlines (Turkey)*

14 June 2009: Boeing 737-400, TC-TLA approach to Diyarbakir airport Turkey (LTCC). Normal approach without autopilot engaged, but with autothrottle engaged. During flare at 20 ft, the aircraft started an unintentional steep climb with an approximatley 40° high nose over a period of 14 seconds. The pilots disengaged the aircraft's autothrottle, ran the aircraft's horizontal stabiliser trim to the full forward position and pushed the control column forward. Both pilots suffered minor injuries, but the passengers and cabin crew were not injured. The NTSB's investigation discovered that a foreign object had settled in the gap on the left-hand PCU and prevented it from moving. Boeing 737-400 has only one Input crank on the left and right-hand PCUs, as opposed to the Boeing 737 NG series (600-900), which has two Input cranks for each PCU. AIBN refers to this event, because it is similar to Kittilä with regards to blockage of PCU. The Tailwind event has however not with icing to do and differ accordingly in this area from Kittilä.

1.18.3.6 After the incident, the NTSB report, ENG09IA011, contained the following five safety recommendations:

> *Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:*
>
> *Require Boeing to develop a method to protect the elevator power control unit input arm assembly on 737-300 through -500 series airplanes from foreign object debris. (A-11-7)*
>
> *Once Boeing has developed a method to protect the elevator power control unit input arm assembly on 737-300 through -500 series airplanes from foreign object debris as requested in Safety Recommendation A-11-7, require operators to modify their airplanes with this method of protection. (A-11-8)*
>
> *Require Boeing to redesign the 737-300 through -500 series airplane elevator control system such that a single-point jam will not restrict the movement of the elevator control system and prevent continued safe flight and landing. (A-11-9)*

Once the 737-300 through -500 series airplane elevator control system is redesigned as requested in Safety Recommendation A-11-9, require operators to implement the new design. (A-11-10)

Require Boeing to develop recovery strategies (for example, checklists, procedures, or memory items) for pilots of 737 airplanes that do not have a mechanical override feature for a jammed elevator in the event of a full control deflection of the elevator system and incorporate those strategies into pilot guidance. Within those recovery strategies, the consequences of removing all hydraulic power to the airplane as a response to any uncommanded control surface should be clarified. (A-11-11)

1.18.4 Planned measures from Boeing

As a result of AIBN and Boeing's investigations, Boeing established in April 2013 the case document "Uncommanded Pitch Up – Elevator PCU Input Lever Restriction. Safety Related Problem 737NG-SRP-27-0237[16]". The SRP was later closed on the basis of root cause determination (ice accretion on the elevator actuator inputs) and procedural changes to meet this.

1.18.4.1 *Changed Boeing procedures*

Norwegian Air Shuttle and Norwegian Air Norway (NAN) uses the Standard Operating Procedures (SOP) issued by Boeing.

Before the Kittilä incident, the procedures from Boeing indicated that the horizontal stabiliser trim on Boeing 737 should be set to the full forward position during de-icing. This would make it easier for de-icing fluid to flow aft and downwards from the horizontal stabiliser and elevator.

After the Kittilä incident and with a basis in the fact that AIBN had discovered fluid penetration in the Tail Cone Compartment, Boeing calculated that, if the horizontal stabiliser trim was set to the centre area on the green band, this would reduce the physical opening in the Tail Cone Compartment. Boeing was thus of the opinion that the fluid penetration would be reduced.

The new draft procedure was presented to AIBN before Boeing announced the changed procedures. AIBN conducted a spray test no. 4 in order to evaluate the change in the volume of fluid penetration at different positions of the horizontal stabiliser trim.

The simulations showed that, by changing the stabiliser trim position from the full forward position to the centre part of the green band, this reduced the fluid penetration, but a considerable volume of fluid still entered the Tail Cone Compartment and splashed in the direction of the Input cranks on the Power Control Units. AIBN's investigation results were communicated to Boeing.

Boeing decided to change their procedures in the Flight Crew Operations Manual (FCOM) so that the horizontal stabiliser trim on Boeing 737 hereinafter should be placed in "green band" during de-icing.

[16] The document is Boeing proprietary.

Furthermore, in October 2013, on the basis of AIBN's investigations, Boeing changed its procedures in the Boeing 737 Aircraft Maintenance Manual (AMM) so that application of de-icing fluid should take place at an angle from the front and not from the side. Boeing 737 should hereinafter be in the centre area of the green band during de-icing.

1.18.4.2 *Plan to modify all Boeing 737s*

In August 2013, Boeing informed AIBN that change of procedures regarding stabilizer position and de-ice direction was not intended to fully mitigate the ingress of fluid towards the elevator system in the Tail Cone Compartment. Based on the engineering geometric analysis, Boeing still expected fluid to get inside the cavity.

Boeings long term mitigation strategy was to make some sort of change of the design of the system which will prevent fluid impingement onto the control system components. In that connection, Boeing informed they planned to modify all Boeing 737s in the interest of achieving better protection against spray into the Tail Cone Compartment and towards components belonging to the elevator system.

Later, Boeing notified AIBN that the considered changes would introduce an unacceptable risk of Foreign Object Debris (FOD) that could impair safety negatively.

1.19 Useful or effective investigation techniques

1.19.1 As described in Chapter 1.16.5, AIBN, on the recommendation of the NTSB, requisitioned a CT scan of both elevator Power Control Units that were in LN-DYM during the incident. The scan took place at Varian Medical Systems in Lincolnshire, Illinois, USA.

1.19.2 The purpose was to uncover any internal defects or foreign objects that may have prevented the PCUs from functioning as intended. It was desirable to clarify this before the units were subsequently opened for internal inspection. The method turned out to be highly useful and effective.

1.19.3 Powerful equipment was used during the CT scan, with a voltage of 1 MeV being used to generate the x-ray beam. A total of 655 cross sectional images were created along the PCU's at a spacing of 0.4 mm. Each pixel within each cross sectional image measured 0.137 x 0.137 mm. All cross sectional images were then imported by NTSB into a 3D computer program that made it possible to present clear images of the internal components (see example in Figure 19).

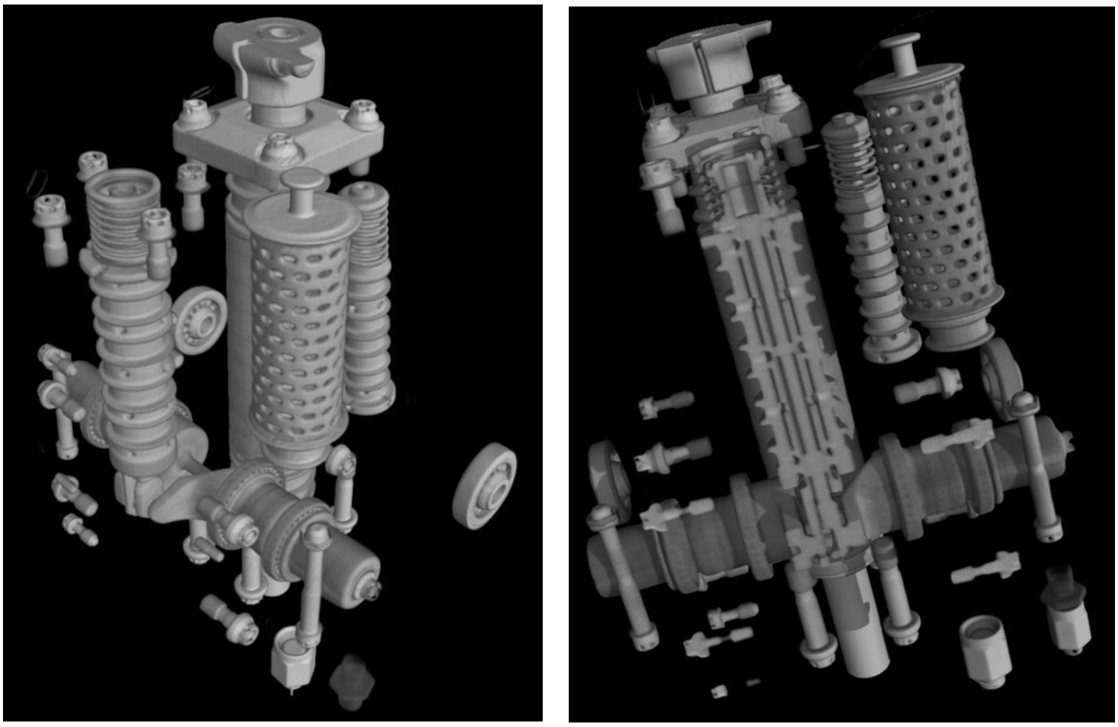

Figure 19: Example images from the CT scan. Photo: NTSB

2. ANALYSIS

2.1 Introduction

2.1.1 Severity of the incident

2.1.1.1 AIBN has classified this incident as serious. LN-DYM was near of stalling, which would most likely have resulted in a total loss. The aircraft was relatively low above the terrain and in clouds, and it would have been difficult for the pilots to regain control of the aircraft with an elevator system that did not function as intended.

2.1.1.2 However, this assessment in retrospect is in contrast to how the flight crew first perceived the incident and that the aircraft continued to operate as normal. Norwegian Air Shuttle decided to immediately route the aircraft to Gardermoen when Boeing, as a result of the analysis of data from the aircraft's flight recorder, issued a recommendation to replace both elevator PCUs on LN-DYM. This is in AIBN's opinion descriptive of the severity of the incident.

2.1.2 Structure of the analysis

In the following, we will first address the sequence of events and the dispositions taken by the flight crew. Thereafter the investigation's benefit of data from flight recorders (see Chapter 2.3) will be discussed. In Chapter 2.4, we will discuss the blockage of the elevator system on Boeing 737 and the need for modification to prevent this blockage. Then we will discuss procedures and training of pilots in Norwegian and whether this may have had an impact on the crew's handling of the incident (see Chapter 2.5). Based on the fact that the aircraft continued to operate, notification of the incident will be addressed in Chapter 2.6. In Chapter 2.7 we will discuss factors that AIBN believes can be excluded from the incident.

2.2 Incident analysis

2.2.1.1 AIBN's investigations of the flight data show that, while en route at cruising altitude to Kittilä on 26 December 2012, the elevator on LN-DYM had gradually become blocked. However, there were no error indications on the flight deck, and the pilots perceived the flight as normal until the aircraft was in the process of being established on the glide slope for approach. As a result of the mentioned blockage and because autopilot commanded stabilizer trim to change angle on horizontal stabilizer, this resulted the aircraft's nose to unintentionally pitch up rapidly and to a dangerous steep angle. The pilots had to use their full force in an attempt to lower the aircraft's nose angle. The pilots did not perform measures that would have improved the situation (disengaging the aircraft's autopilot, autothrottle and/or reducing engine thrust) were not initiated before at a late sequence of the scenario.

2.2.1.2 The AIBN have not decided which procedure mentioned in Chapter 1.17.2.4 that should have been used. The general guideline in Boeing/Norwegian's operational procedures was, and is, to return to manual flying by disengaging the autopilot and autothrottle, which was not done in this case. Only when the aircraft's nose position passed +35°, on its way down, was the stabiliser trim activated by the pilots and the autopilot thereby automatically disengage. As mentioned in Chapter 1.1.2.5, the commander has explained that he thought the aircraft's autopilot had disengaged automatically when the aircraft's nose was in the process of rising. The aircraft eventually passed the definition of an Upset situation (e.g. more than +25° nose position), and the procedures indicate return to manual flying. The commander believing that the autopilot had already been disengaged may explain why the pilots still did not disengage the autopilot. Several of the company's pilots AIBN has talked with have understood that the autopilot disengages automatically when there is used great force on the control column.

2.2.1.3 AIBN presumes that the pilots' concentration was diverted as a result of the aircraft's elevator system not functioning as expected. When the aircraft's nose angle is high and the airspeed declines, it is not natural for a pilot to reduce engine thrust. In this instance, reduced engine thrust, would have greatly improved the situation.

2.2.1.4 As described in Chapter 1.1.2, the pilots were successful in slowly lowering the nose angle, but the elevator only responded at 1:250 ratio of what is normal and expected by the pilots. AIBN is of the opinion that this was most likely the cause of over-correcting and the aircraft ending up in a new abnormal situation. There is much to indicate that the blockage disappeared during this period and that the full force applied through the elevator control column led to an over-correction with subsequent Stick Shaker and stall warning for four seconds.

2.2.1.5 See Chapter 2.5 that addresses procedures and flight crew training in Norwegian.

2.3 Data from flight recorders

2.3.1 <u>Flight recorder</u>

Data from the aircraft's flight recorder have been essential in this investigation as regards the ability to clarify details in the course of events and establish that the aircraft's two elevator Power Control Units were blocked, thus preventing normal operation of the elevator system. AIBN's further investigations have focused on identifying what may have caused the blockage.

2.3.2 Cockpit Voice Recorder (CVR)

2.3.2.1 AIBN consider that the Kittilä flight crew had not perceived that they had experienced a reportable incident and thus they did not have a reason to secure the CVR recording. This is substantiated also by the fact that the crew later chose to fly back to Helsinki as normal.

2.3.2.2 Recordings on CVRs are important material for investigative authorities in order to better be able to map, understand and analyse a course of events and the crew's actions and crew resource management (CRM) in this context. Access to audio recordings on the cockpit voice recorder may have been of interest in this investigation as well.

2.4 Blockage of the elevator system on Boeing 737

2.4.1 Fluid penetration in the Tail Cone Compartment and exposure of PCUs

2.4.1.1 Early analysis of flight data determined that the aircraft's right-hand elevator Power Control Unit had been blocked. Subsequent analysis indicated that minimum three of the aircraft's total of four Input cranks on the PCUs eventually became increasingly blocked while the aircraft was at cruising level, and were then completely blocked during the approach to Kittilä.

2.4.1.2 Because no remnants of foreign objects were found on the Input cranks, and based on completed investigations and analyses from Boeing, AIBN consider that ice on the Input cranks prevented normal operation of the aircraft's elevator.

2.4.1.3 AIBN's investigations discovered that considerable volumes of fluid and humidity enter the Tail Cone Compartment on the Boeing 737 aircraft type and that all four Input cranks on the aircraft type's two elevator PCUs are exposed to spray from the fluid penetration. This in combination with cold metallic Input cranks may result in ice forming in the narrow gap (ref. Figure 8). This prevents normal operation of the elevator. AIBN is of the opinion that ice most likely blocked LN-DYM's elevator on 26 December 2012.

2.4.1.4 It is not possible to establish with 100 % certainty what caused the blockage of the Input cranks to eventually cease, but AIBN finds it likely that the blockage consisted of ice particles in the gap on the Input cranks and that the ice particles were eventually crushed when the pilots exerted their full force on the elevator control column. The hydraulic oil at 3 000 psi pressure inside the PCUs and heat from this may also have contributed toward melting the ice. This may explain why the aircraft behaved as normal on approach number two to Kittilä, as well as during the later flights.

2.4.2 De-icing

2.4.2.1 Due to the large amount of snow on the aircraft (approximately 25 cm), it was necessary to use a large volume of de-icing fluid (approximately 3 000 liters). AIBN's investigation shows that the fluid penetration issue is independent of the volume of de-icing fluid, but cannot exclude that the volume of de-icing fluid and snow better facilitated the formation of ice on the PCU Input cranks. The fluid volume contributes to raise the humidity in the compartment and in combination with the amount of snow it could have diluted the de-icing fluid sufficiently to increase the freezing point.

2.4.2.2 AIBN has assessed the de-icing company's procedures for de-icing aircraft, as well as the report from the company (see Appendix D) that performed the de-icing in Helsinki. AIBN is of the opinion that the de-icing was done in accordance with stipulated procedures. However, AIBN recognises that it is normal to remove more of the snow with other methods than fluid before the de-icing takes place.

2.4.2.3 The investigation has shown that it has been one occurrence with partly blockage, even without prior de-icing (ref. 1.18.3.1 and incident on 22. February 2014). This may indicate that the construction enables high humidity in the compartment, and that this alone can contribute to the formation of ice.

2.4.3 Need for measures to eliminate blockage of Input cranks

2.4.3.1 Both AIBN and Boeing consider that the consequence in an incident with blocked Input cranks can be catastrophic. AIBN's investigation has uncovered that the introduction of new procedures from Boeing (ref. 1.16.8) have reduced humidity and fluid penetration to the Tail Cone Compartment, but it is not eliminated. In Chapter 1.18.3.1 it is mentioned two specific incidents after the new procedures, in which it was necessary to use greater force on the elevator control column than normal. AIBN thus believes that the likelihood of blockage of Input cranks has not been eliminated. There will still be a possibility of ice formation in the PCU Input cranks on Boeing 737s that are de-iced and operate in a cold environment.

2.4.3.2 AIBN believes there is a need for measures that better prevent ice formation on the Input cranks and thus the risk of blocking the elevator on the Boeing 737 aircraft type. The AIBN questions whether the FAA and EASA certification provisions (see Chapter 1.18.2) are satisfied. The AIBN is therefore issuing safety recommendations to Boeing and the two certification authorities FAA and EASA regarding this. In this context, reference is made to safety recommendations A-11-7 and A-11-8 from the NTSB (see Chapter 1.18.3.5) concerning protection of Input cranks on elevator PCUs on the Boeing 737 300-500 series.

2.4.3.3 AIBN's investigation has shown that the issue of humidity and fluid penetration and subsequent ice formation on the Input cranks is independent of the Boeing 737 Classic (100-500 series) and the NG series (600-900 series). This incident occurred on an NG individual with four PCU Input cranks, which should be less vulnerable to blockage than the Classic with its two Input cranks.

2.5 Norwegian – procedures and training

2.5.1 Procedures in Norwegian Air Shuttle

2.5.1.1 Norwegian Air Shuttle uses standard procedures[17] from the aircraft manufacturer and has thus adopted the latest revision from Boeing. The new procedures specify at which angles de-icing fluid should be applied to the Boeing 737 Tail Cone and that the horizontal stabiliser trim must be in the neutral position.

2.5.1.2 As regards the company's operational procedures and checklists as reproduced in Chapter 1.17.2, these are also based on standard procedures from Boeing. AIBN is of the opinion that there are a number of different procedures to relate to which separately improve the

[17] With certain minor exceptions.

situation that occured. In acute situations such as in this instance, the time and opportunity to read checklists is non-existent. The content must therefore be drilled and as a minimum it should be expected to return to manual flying by disengaging the autopilot and autothrottle, which is the common denominator in the procedures. As discussed in Chapter 2.2 this was not done by the flight crew in this incident.

2.5.1.3 AIBN has not identified a need for changes to the company's operative aviation procedures as a result of the incident in Kittilä. However, AIBN sees the need for additional focus on flight crew training.

2.5.2 Flight crew training

2.5.2.1 AIBN has found that the pilots were experienced and had undergone training beyond the authorities' minimum requirements. In spite of this, the incident was not handled in an optimum manner. Applicable procedures show a common denominator of return to manual flying when such situations occur. This was not done, which is a repeat offence in many accidents and incidents in international aviation. When such an unexpected situation occurs, the automatic reflex must be to return to manual flying.

2.5.2.2 AIBN believes that training must be carried out at a quality and volume which ensure the establishment of this automatic reflex. AIBN is therefore of the opinion that training and system understanding must receive additional focus, but issues no safety recommendation in this connection. Reference is also made in this connection to safety recommendation A-11-11 from the NTSB in connection with the serious incident involving a Boeing 737-400 in Turkey in 2009 (see Chapter 1.18.3.5). See Appendix B and C.

2.5.2.3 AIBN is of the opinion that Norwegian has a training concept which seems to be well-founded. The company's account of its philosophy, plans and implementation appears to be well thought-through. AIBN would like to commend the company for exceeding the authorities' minimum requirements as regards theoretical instruction, simulator training, and training in connection with various sectors for commercial flights. In spite of this, the flight crew did not seem to have sufficient system understanding and automatic reflex to handle the incident in an optimum manner. AIBN considers that the aviation industry must focus continually on this aspect given the increasing automation in the cockpit.

2.6 Incident notification

2.6.1 AIBN is of the strong opinion that LN-DYM should have been grounded at Kittilä after the incident occurred. This is because the reason for the serious control issues had not been clarified, which meant that the aircraft's air-worthiness had not been verified. The pilots suspected a temperature inversion, but as a result of the second approach being normal, they should have reconsidered whether this could have caused the incident (see Chapter 2.7.1).

2.6.2 As mentioned, AIBN does not have the details of the conversation from the crew to the Maintenance Control Center (MCC). This means that AIBN do not have the ability to assess whether the MCC should have understood the severity of the incident. The intention in the company's procedures requires that the on-call chief pilot should have been contacted by the commander before the next departure. The severity was also absent from the communication that took place between the commander and the Director Flight Operations (as then was on-call) two days later, the severity of the incident was not expressed.

2.6.3 When the Kittilä incident occurred, Norwegian did not record telephone calls (or calls via VHF radio at Gardermoen) to their Maintenance Operations Center (MOC). AIBN is of the opinion that the company would benefit from recording such conversations. A recording can clarify what information was communicated, clear up any deviations from the desired handling of a situation, clear up any misunderstandings and provide learning from them. It is presumed that, if such a system is established, procedures will be developed for in which situations and who has the authority to review the recordings and how they can be used. For example, conversations to and from emergency agencies in Norway are recorded in order to improve routines.

2.6.4 As mentioned in Chapter 1.17.4.2, Norwegian has informed AIBN that they now do record all audio in to MOC and OCC.

2.6.5 In connection with the draft of this report, AIBN had the following draft safety recommendation:

> *Affected personnel in Norwegian did not perceive the severity of the incident and LN-DYM was therefore not grounded at Kittilä. The crew inquired with the company's centre for maintenance control, but this conversation was not registered. AIBN is of the opinion that the company would benefit from recording such conversations. A recording can clarify what information was communicated, clear up any deviations from the desired handling of a situation and any misunderstandings can form the basis for learning.*
>
> *AIBN recommends that Norwegian consider the need for audio recordings and electronic storage of conversations to and from the company's Maintenance Operations Center (MOC).*

2.6.6 AIBN abstain from proposing the mentioned safety recommendation, in assurance that Norwegian now has implemented this.

2.7 Factors that can be excluded from the incident

2.7.1 Temperature inversion

Relatively significant temperature inversions are not uncommon during an approach. AIBN is of the opinion that, even a significant temperature drop during approach will not cause an aircraft to behave abnormally. AIBN therefore believes that the temperature inversion LN-DYM flew through did not contribute to the incident. This is also substantiated by the fact that LN-DYM and two other Boeing 737-800s from a different airline had uneventful approaches shortly afterwards.

2.7.2 Flight Control Computer

2.7.2.1 AIBN is of the opinion that the active Flight Control Computer (position A) functioned as intended during the phase of the flight where the incident occurred.

2.7.2.2 AIBN also believes that the mentioned error codes in connection with Mach Trim in the Flight Control Computer (position B), had no effect on the course of events.

2.7.3 Hydraulic oil and filter

Laboratory tests of the hydraulic oil drained from LN-DYM showed deviations in the form of colour, odour and particle content. The results from analysis were outside the specifications from the hydraulic oil manufacturer, but within the specifications issued by Boeing for use in this aircraft type. AIBN is of the opinion that these deviations did not contribute to the incident in Kittilä, but does not exclude the possibility that the change in colour and odour may have occurred in connection with the blocked PCUs. AIBN also questions how mineral particles have entered the hydraulic system. Except from change of filters and refill of hydraulic oil, it had not been performed any work on the hydraulic systems since LN-DYM was delivered as new from the Boeing factory.

3. CONCLUSION

3.1 Material investigation results of significance for aviation safety

a) During its approach to Kittilä, LN-DYM was close to stalling. The outcome of a stall could have been catastrophic.

b) The analysis of data from the flight data recorder shows that three or four of the Input cranks on the aircraft's elevator Power Control Units were blocked, most likely due to ice. Calculations made by Boeing indicate that the elevator was extremely slow in responding. With only 0.2°/second, compared with the normal 50°/second. This indicates 1:250 compared with the normal response. At the end of the scenario, the blockage ceased.

c) Fluid and humidity will penetrate the Tail Cone Compartment in connection with de-icing of Boeing 737. Increased humidity and spray settling on cold Input cranks may result in ice formation.

d) AIBN's investigation has documented that, even after the introduction of new de-icing procedures from Boeing, large volumes of fluid and pertaining humidity can enter the Tail Cone Compartment during de-icing.

e) AIBN questions whether certification requirements in FAR Part 25 § 25.671 and EASA CS-25 §25.671 for the Boeing 737 Classic and Next Generation series are satisfied.

f) AIBN believes that training must be carried out at a quality and volume which ensure the establishment of system understanding and the automatic reflex of return to manual flying.

g) LN-DYM should have been grounded at Kittilä after the incident occurred. This is because the background of the serious control issues had not been clarified, which meant that the aircraft's air-worthiness had not been verified.

3.2 Investigation results

a) Norwegian Air Shuttle possessed the necessary AOC and rights to conduct commercial air transport on the relevant route and with the relevant aircraft.

b) The aircraft was registered according to the regulations and had a valid Airworthiness Review Certificate (ARC).

c) The aircraft's mass and the location of its centre of gravity were within the permitted limits at the time of the incident.

d) No technical faults or irregularities on the aircraft were identified which AIBN believes may have affected the course of events.

e) Norwegian Air Shuttle mainly uses standard technical and operational procedures based on the aircraft manufacturer Boeing’s guidelines.

f) Norwegian Air Shuttle's operational procedures for situations such as the relevant incident were comprehensive and in accordance with the manufacturer’s recommendations.

g) Norwegian Air Shuttle's training program for pilots exceeded the authorities' minimum requirements.

h) The crew members had valid certificates and privileges for the aircraft type.

i) The pilots had completed the company's training program and the relevant commander had recently trained for loss of control at low altitude.

j) The de-icing performed prior to departure appears to have been carried out according to applicable procedures.

k) Large amounts of snow were not removed before the de-icing started and it was necessary to use large volume of de-icing fluid.

l) The aircraft was flown with the autopilot and autothrottle engaged, and the aircraft's configuration and airspeed was normal prior to the incident.

m) The aircraft was established on the localizer and was in the process of being established on the glide slope, when the aircraft started an unintentional, steep climb.

n) Measures at an early stage that would have improved the situation (disengaging the aircraft's autopilot, autothrottle and/or reduced engine power) were not performed.

o) The general guideline in Boeing/Norwegian's operational procedures was, and is, to return to manual flying by disengaging the autopilot and autothrottle.

p) The pilots had to use their full force in an attempt to lower the aircraft's nose angle.

q) The analysis of data from the flight data recorder shows that the Input cranks on the aircraft's elevator Power Control Units were gradually blocked en route at cruising level.

r) The issue of de-icing fluid and humidity penetrating the Tail Cone Compartment on Boeing 737 applies to both the Classic and Next Generation series.

s) When the Kittilä incident happened, Norwegian did not record telephone calls to and from its Maintenance Control Center (MOC). The company has later implemented recording of telephone calls to and from MOC and Operations Control Center (OCC).

4. SAFETY RECOMMENDATIONS

The Accident Investigation Board Norway (AIBN) makes the following safety recommendations:

Safety recommendation SL 2015/01T

During its approach to Kittilä on 26 December 2012, LN-DYM came close to stalling as a result of a blocked elevator. AIBN's investigation has documented that, even after the introduction of new de-icing procedures from Boeing, considerable volumes of fluid and pertaining humidity are penetrating the Tail Cone Compartment during de-icing of the Boeing 737 aircraft type. The investigation shows fluid penetration toward the four Input cranks on the aircraft's two Power Control Units. If this fluid freezes in the narrow gap between the Input cranks, this may result in blockage of the Power Control Units. This prevents operation of the elevator on Boeing 737 with potentially catastrophic outcome.

AIBN recommends that the aircraft manufacturer Boeing conduct a new safety assessment of the Boeing 737 aircraft type as regards blockage of the aircraft type's elevator system, and establish measures in order to satisfy the requirements in FAR Part 25 § 25.671 and EASA CS-25 §25.671. (Similar safety recommendations are also issued to the FAA and EASA).

Safety recommendation SL 2015/02T

During its approach to Kittilä on 26 December 2012, LN-DYM came close to stalling as a result of a blocked elevator. AIBN's investigation has documented that, even after the introduction of new de-icing procedures from Boeing, considerable volumes of fluid and pertaining humidity are penetrating the Tail Cone Compartment during de-icing of the Boeing 737 aircraft type. The investigation shows fluid penetration toward the four Input cranks on the aircraft's two Power Control Units. If this fluid freezes in the narrow gap between the Input cranks, this may result in blockage of the Power Control Units. This prevents operation of the elevator on Boeing 737 with potentially catastrophic outcome.

AIBN recommends the FAA to ensure that the aircraft manufacturer Boeing conduct a new safety assessment of the Boeing 737 aircraft type as regards blockage of the aircraft type's elevator system, and that the analysis result and established measures satisfy the requirements in FAR Part 25 § 25.671 . (Similar safety recommendations are also issued to Boeing and EASA).

Safety recommendation SL 2015/03T

During its approach to Kittilä on 26 December 2012, LN-DYM came close to stalling as a result of a blocked elevator. AIBN's investigation has documented that, even after the introduction of new de-icing procedures from Boeing, considerable volumes of fluid and pertaining humidity are penetrating the Tail Cone Compartment during de-icing of the Boeing 737 aircraft type. The investigation shows fluid penetration toward the four Input cranks on the aircraft's two Power Control Units. If this fluid freezes in the narrow gap between the Input cranks, this may result in blockage of the Power Control Units. This prevents operation of the elevator on Boeing 737 with potentially catastrophic outcome.

AIBN recommends EASA to ensure that the aircraft manufacturer Boeing conduct a new safety assessment of the Boeing 737 aircraft type as regards blockage of the aircraft type's elevator system, and that the analysis result and established measures satisfy the requirements in EASA CS-25 §25.671. (Similar safety recommendations are also issued to Boeing and the FAA).

The Accident Investigation Board Norway

Lillestrøm, 25. March 2015

APPENDICES

Appendix A: Abbreviations

AC	Alternating current
AFM	Aircraft flight manual
AIC	Aeronautical information circular
AIP	Aeronautical information publication
AMM	Aircraft maintenance manual
AMSL	Above Mean Sea Level
AOA	Angle Of Attack
APP	Approach control
ASDA	Accelerate-stop distance available
ATPL (A)	Airline transport pilot license (aeroplane)
BSL E	Provisions for civil aviation concerning aviation facilities and ground services
CAA	Civil aviation authority
CAS	Calibrated Airspeed
CPL (A)	Commercial pilot license (aeroplane)
CRM	Crew resource management
CVR	Cockpit voice recorder
CWY	Clearway
DC	Direct current
DME	Distance Measuring Equipment
DVOR / VOR	Doppler VOR / VHF Omnidirectional Radio Range
EMERG	Emergency
ESS	Essential
FDR	Flight data recorder
FEW	Few
hPa	Hectopascal

IAS	Indicated airspeed
ICAO	International Civil Aviation Organization
IMC	Instrument Meteorological Condition
IR (A)	Instrument rating (aeroplane)
JAR	Joint aviation requirements
JAR-OPS 1	Joint aviation requirements – operations – fixed wing
JAR-145	Joint aviation requirements – maintenance
Kt	Knots
LDA	Landing distance available
Lb	Pound
MAN	Manual
ME	Multi engine
MPA	Multi pilot aeroplane
ME/MP	Multi engine/multi pilot
MEP	Multi engine piston
METAR	Aerodrome routine meteorological report
MSL	Mean sea level
N1	Term for % rotation speed in the engine's 1st compressor stage
NG	Next Generation
NM	Nautical miles
QNH	Altimeter sub-scale setting to obtain elevation when on ground
OPC	Operator proficiency check
PAPI	Precision approach path indicator
PC	Proficiency check
RWY	Runway
SARPS	Standards and recommended practices (ICAO)
SAT	Saturated Air Temperature

SEP	Single engine piston
SOP	Standard operating procedures
SW	South-west
TAF	Terminal aerodrome forecast
TAT	Total Air Temperature
THR	Threshold
TMA	Terminal area
TWR	Tower
UTC	Universal time coordinated
VCS	Voice communication system
VRB	Variable

National Transportation Safety Board
Washington, D.C. 20594

Safety Recommendation

Date: February 10, 2011

In reply refer to: A-11-7 through -11

The Honorable J. Randolph Babbitt
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On June 14, 2009, about 1817 Coordinated Universal time, a Boeing 737-400 (737), registration number TC-TLA, operated as Tailwind Airlines flight OHY036, experienced an uncommanded pitch-up event at 20 feet above the ground during approach to Diyarbakir Airport (DIY), Diyarbakir, Turkey.[1] The flight crew performed a go-around maneuver and controlled the airplane's pitch with significant column force, full nose-down stabilizer trim, and thrust. During the second approach, the flight crew controlled the airplane and landed by inputting very forceful control column inputs to maintain pitch control. Both crewmembers sustained injuries during the go-around maneuver; none of the 159 passengers or cabin crewmembers reported injuries. The airplane was undamaged during the scheduled commercial passenger flight. The Turkish Directorate General of Civil Aviation, acting on behalf of the State of Occurrence, delegated the investigation to the National Transportation Safety Board (NTSB). The NTSB investigated this incident under the provisions of International Civil Aviation Organization Annex 13 as the Country of Manufacture and Design of the airplane.

The NTSB's investigation found that the incident was caused by an uncommanded elevator deflection as a result of a left elevator power control unit (PCU) jam due to foreign object debris (FOD). The FOD was a metal roller element (about 0.2 inches long and 0.14 inches in diameter) from an elevator bearing. During its investigation of this incident, the NTSB identified safety issues relating to the protection of the elevator PCU input arm assembly, design of the 737 elevator control system, guidance and training for 737 flight crews on a jammed elevator control system, and upset recovery training.

[1] More information regarding this incident, National Transportation Safety Board case number ENG09IA011, is available online at <http://www.ntsb.gov/ntsb/query.asp>.

Protection of the Elevator PCU Input Arm Assembly

Boeing 737-300 through -500 series airplanes'[2] primary pitch control[3] is provided by two hydraulically powered elevators with manual reversion[4] available in the event of a loss of hydraulics. The elevators are controlled by forward and aft motion of the captain's and first officer's control columns, which are connected to each other via a torque tube with a forward cable control quadrant mounted at each end. Elevator control cables are routed from the quadrants' aft end and attach to a pair of aft elevator control quadrants, which are mounted on the lower elevator input torque tube.[5] This tube is mechanically connected, via linkages, to each PCU input arm assembly, which, when rotated, provides a simultaneous command to each PCU to extend or retract.[6] The output rod of each PCU is connected to the upper torque tube, which is directly linked by pushrods to each elevator (see figure). The elevator PCUs are located in the tail of the airplane.

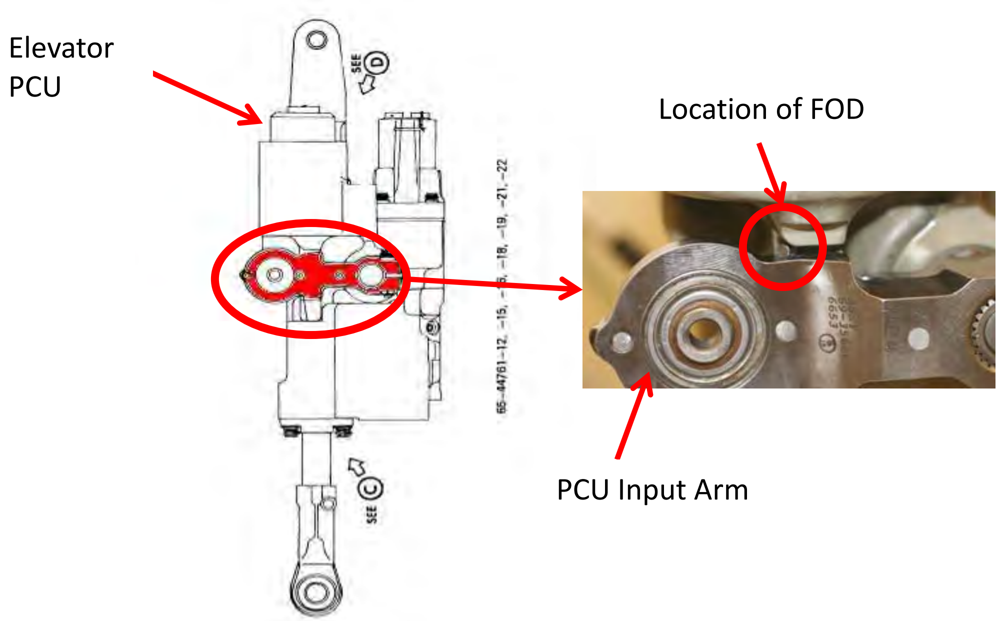

Figure. Location of FOD.

[2] While 737-100 and -200 series airplanes are similar in design to 737-300 through -500 series airplanes, the NTSB notes that 737-100 series airplanes are no longer in service, and 737-200 series airplanes are no longer operated by U.S. carriers.

[3] The design of the 737-600 through -900 series airplanes' pitch control system is different from that on 737-300 through -500 series airplanes; these differences are discussed in the "Design of the 737 Elevator Control System" section of this letter.

[4] "Manual reversion" means "without hydraulic power." In manual reversion mode, the pilot can control the elevators and ailerons by movement of the control column or wheel, respectively, but the control forces will be much higher than with hydraulics.

[5] The aft elevator controls are located in the empennage aft of the stabilizer rear spar.

[6] The two PCUs operate in unison, and each is powered by a separate and independent hydraulic system (the left unit from hydraulic system "A" pressure and the right unit from hydraulic system "B" pressure).

Tailwind Airlines' postincident inspection of the elevator PCUs revealed that the system "A" elevator PCU input arm assembly was jammed by a piece of FOD (a metal bearing roller) in a position that offset the control arm in a downward direction. With the control arm deflected downward and with hydraulic pressure available, the PCU would be commanded to move the elevator to a position that would pitch the aircraft nose up. The incident airplane's flight data recorder (FDR) recorded an aircraft pitch up during the landing flare just before the commanded go-around maneuver. Because of the way the elevators are linked together, a jam in one PCU will cause both elevator surfaces to deflect in the same direction. (The two sides of the system cannot be disconnected so that the unjammed PCU can control the elevators.)

In January 2009, a scheduled maintenance check ("C" check) was performed on the airplane. Part of the check involved replacement of the upper torque tube output crank bearing. Postincident inspections of the airplane's elevator system components located within the tailcone also revealed that the left elevator upper torque tube output crank bearing/sleeve appeared new, with all bearings present. The NTSB determined that, at some point during maintenance or in-service operation before the January 2009 maintenance check, metal rollers[7] became dislodged from the bearing and scattered throughout the aft elevator system components.

During its investigation of this incident, the NTSB noted that the 737 aileron control system uses PCUs identical to those located in the elevator control system. FOD contamination is considered more likely in the aileron control system due to the location of the aileron PCUs in the main landing gear (MLG) wheel well. This area is exposed to the external environment whenever the MLG is extended, and the flight control components are vulnerable to damage from environmental debris or tire failure. Protective modifications had to be accomplished[8] on specified flight control components located in the wheel well. Two of these components, the aileron PCUs, were modified by the incorporation of protective soft covers over the input arm assembly of each aileron PCU.

The NTSB notes that the protective covering used for the aileron input arm assemblies would likely also help protect the elevator PCUs on 737-300 through -500 series airplanes from FOD. The NTSB concludes that FOD within any flight control system is a serious concern because debris may migrate and become lodged within the controls, resulting in a jam of the control system during a critical phase of flight. Further, the NTSB concludes that special protection (in the form of protective covering or other methods) for the elevator PCUs would ensure that FOD does not jam the elevator PCU input arm assembly. Therefore, the NTSB recommends that the Federal Aviation Administration (FAA) require Boeing to develop a method to protect the elevator PCU input arm assembly on 737-300 through -500 series airplanes from FOD. The NTSB further recommends that the FAA, once Boeing has developed a method to protect the elevator PCU input arm assembly on 737-300 through -500 series airplanes from

[7] In addition to the metal bearing roller that caused the jam, a second metal bearing roller was found resting at the bottom of the tailcone near the drain hole, mostly buried in debris. Boeing's metallurgical analysis revealed that both metal bearing rollers had the same dimensions and material as the rollers that are installed in two locations in the aft elevator control system (the right and left ends of the elevator upper output torque tube crank assembly).

[8] In July 1987, Boeing issued Service Bulletin 737-52-109 to remove the MLG wheel well tire burst protector screen doors on all 737 airplanes that are so equipped. The Federal Aviation Administration (FAA) did not issue an airworthiness directive to mandate this service bulletin. For more information, see FAA B737 Flight Control System Critical Design Review, dated May 3, 1995.

FOD as requested in Safety Recommendation A-11-7, require operators to modify their airplanes with this method of protection.

Design of the 737 Elevator Control System

The NTSB's investigation of this incident revealed that the flight crew controlled the airplane through the use of full nose-down stabilizer trim, thrust, and effort by both crewmembers to resist the pull action caused by the jam. The forces required to control the airplane were so high that the crewmembers' exertions on the control column resulted in their injuries. The design of the 737-300 through -500 series airplanes does not include any means by which the flight crew can override an elevator control system jam. During its investigation of this incident, the NTSB reviewed the design history of these airplanes, the potential for additional jamming events, and the jam override mechanisms available on other airplane models.

According to the FAA's service difficulty report database, four additional 737-300 through -500 series airplanes experienced events involving binding or jamming of the elevator control system. Although none of these events resulted in an accident, they highlight the fact that binding or jams of the elevator system do occur in flight, can result from numerous causes (including improper maintenance performed on the airplane), and can present the flight crew with controllability hazards. During the first reported event, which occurred on January 14, 1998, the flight crew indicated that the elevator jammed while flaring the airplane for landing and required approximately 50 to 60 pounds of force on the columns to free the elevators. The source of the jam could not be identified. The second reported event occurred on October 12, 2003, during which the flight crew reported stiff controls throughout the flight, and, during the landing flare, the control column bound for a moment and then broke free. The source of the jam could not be identified. During the third reported event on October 16, 2003, the flight crew indicated that the elevator was binding when pulling the control column back to the point of having to use excessive pressure to return the column to neutral. The flight crew reported that the column was completely stuck at one point in the flight. Maintenance crews found a large piece of Velcro lodged between an elevator cable pulley and cable retainer. The elevator system was cycled and found to operate normally after the removal of the Velcro. During the fourth reported event on October 9, 2005, the flight crew aborted takeoff at 140 knots due to no elevator movement. Maintenance personnel discovered that the elevator balance weight from one elevator was lodged between the lower surface of the elevator and the stabilizer, resulting in a jam that prevented both elevators from moving. If this jam had occurred during flight instead of during the takeoff roll, control of the airplane would have been extremely difficult. These reports indicate that jams of the 737 elevator system occur during service, and because the jammed portions of the system cannot be overridden, the flight crews have no option but to try to overpower the jam with excessive force.

Further, a design review of the 737 elevator system has determined that there are additional ways in which the system may become jammed. The NTSB's query of the FAA's airworthiness directive (AD) database revealed that, on November 25, 2005, the FAA issued AD 2005-26-03, "Elevator Input Torque Tube Assembly," for all 737s (737-100 through -900 series airplanes) to prevent the loss of elevator control and subsequent reduced controllability. The AD resulted from a report of a restriction in the pilot's elevator input control system.

Although the cause of the incident was not determined, a design review that Boeing performed on the aft elevator input torque tube assembly during the investigation revealed possible failure modes that could lead to an elevator control system jam. The FAA issued the AD to require operators to take action to prevent these jams.

The NTSB reviewed the 737-300 through -500 series airplane certification requirements and found that even though these airplanes were awarded type certificates between 1984 and 1990, the elevator control system of the 737-300 through -500 series airplanes was considered to be unchanged and carries the same certification basis as the 737-100 and -200 series airplanes (which were certified in 1967).[9] The NTSB's review of the certification data also revealed that even though Boeing had developed flight control system designs that included jam override mechanisms for use in other airplanes before the certification of the 737-300 through -500 series airplanes (such as the 757 and 767 airplanes, which were introduced into service in 1983 and 1982, respectively), these designs were not incorporated into the 737-300 through -500 series airplanes and were not required to be by the FAA.

The NTSB notes that during discussions with the FAA and Boeing regarding elevator jamming incidents, all parties agreed that a jam in the elevator system (either a rate jam or position jam) should be considered a catastrophic hazard. Further, given the age of the 737-300 through -500 series airplanes, the need for maintenance actions in critical areas of the flight control system should be expected to grow, further increasing the possibility of jam-inducing failures caused by FOD, maintenance errors, or other failures which by today's certification standards would require that no single failure in the control system be able to contribute to such a jam. As a result, the NTSB believes that additional design improvements should be considered to mitigate the effects of single-point-induced jams.

The elevator control system on 737-300 through -500 series airplanes comprises two parallel sets of flight control cables (one connected to the captain's side and the other to the first officer's side) that transmit flight control commands from the control columns to the aft elevator input torque tube and then to the elevator PCU input arm via control rods. Because the system does not contain override mechanisms, a single point malfunction (jam) to one side of the control system will effectively jam both sides of the control system, resulting in the partial or complete loss of elevator control. In such a scenario, the flight crewmembers may not be able to exert enough force on both control columns to overcome the jam and would therefore lose control of the elevators.

A review of the elevator control systems on other transport-category airplanes indicates that override mechanisms are commonly installed and aid in maintaining control of the airplane when a system malfunction occurs. For example, Boeing 717, 747, 757, 767, and 777 airplanes; Embraer 120, 145, 170, and 190 airplanes; Bombardier Canadair Regional Jet CRJ-200, CL-600-2B19, DHC-8, and Q400 airplanes; and ATR-42 and -72 airplanes all contain override mechanisms in the elevator system. Further, the elevator system on 737-600 through -900 series airplanes was improved by the addition of several mechanical override mechanisms. While these

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[9] When the 737-100 and -200 series airplanes were certified, 14 *Code of Federal Regulations* Part 25 did not specifically require consideration of a jam resulting from a single failure mode of a device in the control system as long as the failure mode was considered extremely remote.

override mechanisms do not mitigate all possible jam conditions, in general, in the event of a system jam, the mechanisms allow both elevators to be controlled by the movement of the unaffected control column.

The following September 2, 2004, event involving a de Havilland (Bombardier) DHC-8 airplane highlights the benefit of an override mechanism for the elevator control system.[10] The Transportation Safety Board of Canada reported that, during the initial climb following takeoff, the first officer noted that abnormal forward pressure on the control column was required to keep the airplane from pitching nose up. To counter the pitch-up, he trimmed the airplane nose down. About 30 seconds after becoming airborne, the airplane was 350 feet above ground level, and the first officer had applied full nose-down trim. The amount of forward pressure on the control column continued to increase as the airplane accelerated, and the first officer notified the captain of the control difficulties and requested his assistance in holding the control column forward. The flight crew leveled the airplane at 4,000 feet above sea level and pulled the elevator pitch disconnect handle, isolating the left and right elevators. The captain’s elevator control functioned normally after the disconnect, and he continued the flight.[11]

Because of the lack of an override mechanism within the elevator control system on the 737-400 airplane involved in the Tailwind Airlines incident, the flight crewmembers had to exert constant and excessive force on the control columns to overcome the jam. While the flight crewmembers exerted enough force on the control columns to overcome the jam, the NTSB is concerned that other jam scenarios may exist in which pilot inputs would not be enough to successfully control the airplane. Consequently, there may be no assurance of continued safe flight and landing in the event of an elevator control system jam. The NTSB concludes that because the elevator control system on 737-300 through -500 series airplanes does not contain any override mechanisms, a single-point jam-type failure (restriction of any elevator control system components) could result in the loss of elevator system control and could render the airplane uncontrollable. Therefore, the NTSB recommends that the FAA require Boeing to redesign the 737-300 through -500 series airplane elevator control system such that a single-point jam will not restrict the movement of the elevator control system and prevent continued safe flight and landing. The NTSB further recommends that the FAA, once the 737-300 through -500 series airplane elevator control system is redesigned as requested in Safety Recommendation A-11-9, require operators to implement the new design.

Guidance and Training for 737 Flight Crews on a Jammed Elevator Control System

The NTSB determined that the elevator control system on the incident airplane was functioning normally during the flight until the final approach to runway 34 at DIY. FDR data indicated that, about 20 feet above the ground, there was an uncommanded deflection of both

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[10] For more information, see *Flight Control Difficulties, Jazz Air Inc., de Havilland DHC-8-102 C-FGRP, Kingston, Ontario, 02 September 2004*, Aviation Investigation Report A04O0237 (Gatineau, Quebec, Canada: Transportation Safety Board of Canada, 2005).

[11] An inspection after landing revealed that half of one of the balance weights from the right-side elevator spring tab and the nuts that secured it were missing. The two bolts had jammed on the top surface of the elevator and held the elevator spring tab in the trailing-edge-down position.

elevators, resulting in the airplane's pitch attitude increasing from about 4° to about 40° within about 14 seconds. The flight crew reacted immediately to the uncommanded pitch-up event by adjusting the stabilizer trim position to its full nose-down position (0 units) and by attempting to move the elevator control columns forward. FDR data indicated that, once the flight crewmembers reestablished minimal control over the pitching tendency, they turned off the hydraulic power to the flight controls. This action removed the hydraulic pressure from both elevator PCUs, resulting in both elevators deflecting to their neutral (zero hinge moment or float) position. Because the flight crew had just positioned the stabilizer to its full aircraft nose-down position, without the counteracting force of the elevator, the airplane's pitch attitude rapidly changed from +5° to about -5°. The flight crew immediately restored hydraulic power, and the airplane continued to demonstrate significant pitch-up tendencies. The flight crew ultimately controlled the airplane through the use of full nose-down stabilizer, thrust, and effort by both crewmembers on the column.

The flight crewmembers did not have sufficient time to reference the 737 flight crew operations manual (FCOM) or Quick Reference Handbook (QRH). The 737 FCOM provides general guidance for a jammed or restricted flight control and states, in part, that "if any jammed flight control condition exists, both pilots should apply force to try to either clear the jam or activate the override feature." Because the 737-400 does not have a mechanical override feature for a jammed elevator, the pilots needed to try to clear the jam. However, the NTSB's review of the 737 FCOM revealed that there are no checklists or procedures regarding recovery from an uncommanded elevator deflection and/or a jammed elevator control system.

The NTSB notes that an airplane with flight control problems should be handled in a slow, methodical manner by managing the airplane's energy, arresting the flightpath divergence, and recovering to a stabilized flightpath before referencing any written guidance (such as an FCOM, QRH, or quick reference checklist). As demonstrated on the incident flight, when the flight crew turned off hydraulic power, the position of the elevators changed, causing a change in the airplane's pitch attitude due to the nose-down pitch trim that the flight crew had previously applied. The flight crew's immediate actions after the jam of the elevator PCU allowed them to stabilize the airplane to make a go-around maneuver; however, by turning off the hydraulic power during the go-around maneuver, the flight crew adversely affected the airplane's controllability.

The NTSB concludes that, without guidance to flight crews regarding appropriate actions to take in the event of an inoperative or malfunctioning elevator control system, pilots may improvise troubleshooting measures that could inadvertently worsen the condition of a marginally controllable airplane.[12] Therefore, the NTSB recommends that the FAA require Boeing to develop recovery strategies (for example, checklists, procedures, or memory items) for

[12] This was an issue in the January 31, 2000, crash of Alaska Airlines flight 261 into the Pacific Ocean near Anacapa Island, California. Following that accident, the NTSB issued Safety Recommendation A-02-36, which asked the FAA, in part, to "issue a flight standards information bulletin directing air carriers to instruct pilots that in the event of an inoperative or malfunctioning flight control system, if the airplane is controllable they should complete only the applicable checklist procedures and should not attempt any corrective actions beyond those specified." This recommendation was classified "Closed—Acceptable Action" on January 13, 2005.

pilots of 737 airplanes that do not have a mechanical override feature for a jammed elevator in the event of a full control deflection of the elevator system and incorporate those strategies into pilot guidance. Within those recovery strategies, the consequences of removing all hydraulic power to the airplane as a response to any uncommanded control surface should be clarified.

Upset Recovery Training

On October 18, 1996, the NTSB issued Safety Recommendation A-96-120 in response to three uncommanded roll and/or yaw events that occurred while 737 airplanes were approaching to land: the March 3, 1991, United Airlines flight 585 accident in Colorado Springs, Colorado; the September 8, 1994, USAir flight 427 accident near Aliquippa, Pennsylvania; and the June 9, 1996, Eastwind Airlines flight 517 incident in Richmond, Virginia. Safety Recommendation A-96-120 asked the FAA to do the following:

> Require 14 [*Code of Federal Regulations*] CFR Part 121 and 135 operators to provide training to flight[ ]crews in the recognition of and recovery from unusual attitudes and upset maneuvers, including upsets that occur while the aircraft is being controlled by automatic flight control systems, and unusual attitudes that result from flight control malfunctions and uncommanded flight control surface movements.

On January 16, 1997, the FAA responded that many operators are currently providing training on the recognition, prevention, and recovery of aircraft attitudes normally not associated with air carrier flight operations. On August 11, 1999, the FAA indicated that it initiated a notice of proposed rulemaking (NPRM) proposing to revise 14 CFR Part 121, Subparts N and O, to include training in the recognition of and recovery from unusual attitudes and upset maneuvers. The FAA anticipated that the NPRM would be published in December 2000. The FAA later indicated that the NPRM might be published in 2003. The NPRM was published in 2009; however, to date, no regulation has been enacted based on the NPRM.

On October 26, 2004, the NTSB reclassified Safety Recommendation A-96-120 "Open—Unacceptable Response" as part of its report on the crash of American Airlines flight 587 in Belle Harbor, New York.[13] The NTSB notes that 14 years have passed since the issuance of this recommendation, and the FAA has yet to make regulatory changes to address this safety issue. However, the Tailwind Airlines incident supports the need for flight crew training in the recognition of and recovery from unusual attitudes and upset maneuvers. Any training reference material that the FAA uses for upset recovery training course curriculum development should include a description of jammed or restricted flight controls, along with a description of how best to incorporate those recovery strategies to a control malfunction similar to that which occurred in the Tailwind Airlines incident.[14] Such training would likely have provided the incident flight crew with critical information about how to recover from a jammed elevator

[13] See *In-Flight Separation of Vertical Stabilizer, American Airlines Flight 587, Airbus Industrie A300-605R, N14053, Belle Harbor, New York, November 12, 2001,* Aircraft Accident Report NTSB/AAR-04/04 (Washington, D.C.: National Transportation Safety Board, 2004).

[14] Although Tailwind Airlines is not a U.S. carrier, the 737 is used extensively by U.S. carriers with FAA oversight.

control system. The NTSB notes that the initial actions by the flight crew to return the airplane to controllable flight were consistent with the techniques defined in the *Airplane Upset Recovery Training Aid*.[15] The NTSB believes this incident emphasizes the importance of the upset training as recommended in Safety Recommendation A-96-120 so that flight crewmembers can be provided with skills to employ during an airplane upset.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

> Require Boeing to develop a method to protect the elevator power control unit input arm assembly on 737-300 through -500 series airplanes from foreign object debris. (A-11-7)
>
> Once Boeing has developed a method to protect the elevator power control unit input arm assembly on 737-300 through -500 series airplanes from foreign object debris as requested in Safety Recommendation A-11-7, require operators to modify their airplanes with this method of protection. (A-11-8)
>
> Require Boeing to redesign the 737-300 through -500 series airplane elevator control system such that a single-point jam will not restrict the movement of the elevator control system and prevent continued safe flight and landing. (A-11-9)
>
> Once the 737-300 through -500 series airplane elevator control system is redesigned as requested in Safety Recommendation A-11-9, require operators to implement the new design. (A-11-10)
>
> Require Boeing to develop recovery strategies (for example, checklists, procedures, or memory items) for pilots of 737 airplanes that do not have a mechanical override feature for a jammed elevator in the event of a full control deflection of the elevator system and incorporate those strategies into pilot guidance. Within those recovery strategies, the consequences of removing all hydraulic power to the airplane as a response to any uncommanded control surface should be clarified. (A-11-11)

In response to the recommendations in this letter, please refer to Safety Recommendations A-11-7 through -11. If you would like to submit your response electronically rather than in hard copy, you may send it to the following e-mail address: correspondence@ntsb.gov. If your response includes attachments that exceed 5 megabytes, please e-mail us asking for instructions on how to use our secure mailbox. To avoid confusion, please use only one method of submission (that is, do not submit both an electronic copy and a hard copy of the same response letter).

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[15] *Airplane Upset Recovery Training Aid, Revision 1,* Page 3, B-65, states that nose-high, wings-level recovery techniques (pitch attitude unintentionally more than 25°, nose-high and increasing, airspeed decreasing rapidly, ability to maneuver decreasing) include the following: recognize and confirm the situation, disengage autopilot and autothrottle, apply as much as full nose-down elevator, use appropriate techniques, roll to obtain a nose-down pitch rate, reduce thrust (underwing-mounted engines), complete the recovery, approach horizon, roll to wings level, check airspeed and adjust thrust, and establish pitch attitude.

Chairman HERSMAN, Vice Chairman HART, and Members SUMWALT, ROSEKIND, and WEENER concurred in these recommendations.

[Original Signed]

By: Deborah A.P. Hersman
Chairman

Recommendation Report

NTSB Report #: **Rec #: a-11-007,a-11-008,a-11-009,a-11-010,a-11-011**

Notation Id:	8279	**Accident Date:**	06/14/09	**Issue Date:**	02/10/11
City/State:	Diyarbakir,	**NTSB Report #:**		**Most Wanted:**	No

On June 14, 2009, about 1817 Coordinated Universal time, a Boeing 737-400 (737), registration number TC-TLA, operated as Tailwind Airlines flight OHY036, experienced an uncommanded pitch-up event at 20 feet above the ground during approach to Diyarbakir Airport (DIY), Diyarbakir, Turkey.1 The flight crew performed a go-around maneuver and controlled the airplane's pitch with significant column force, full nose-down stabilizer trim, and thrust. During the second approach, the flight crew controlled the airplane and landed by inputting very forceful control column inputs to maintain pitch control. Both crewmembers sustained injuries during the go-around maneuver; none of the 159 passengers or cabin crewmembers reported injuries. The airplane was undamaged during the scheduled commercial passenger flight. The Turkish Directorate General of Civil Aviation, acting on behalf of the State of Occurrence, delegated the investigation to the National Transportation Safety Board (NTSB). The NTSB investigated this incident under the provisions of International Civil Aviation Organization Annex 13 as the Country of Manufacture and Design of the airplane.
The NTSB's investigation found that the incident was caused by an uncommanded elevator deflection as a result of a left elevator power control unit (PCU) jam due to foreign object debris (FOD). The FOD was a metal roller element (about 0.2 inches long and 0.14 inches in diameter) from an elevator bearing. During its investigation of this incident, the NTSB identified safety issues relating to the protection of the elevator PCU input arm assembly, design of the 737 elevator control system, guidance and training for 737 flight crews on a jammed elevator control system, and upset recovery training.

Recommendation # : A-11-007 **Overall Status:** Closed - Reconsidered **Priority:** CLASS II

TO THE FEDERAL AVIATION ADMINISTRATION: Require Boeing to develop a method to protect the elevator power control unit input arm assembly on 737-300 through -500 series airplanes from foreign object debris.

# of Addressees: 1 **Overall Date Closed:** 01/10/13

Addressee: FAA Closed - Reconsidered **Addresee Date Closed:** 01/10/13

04/25/11	Addressee	201100175	CC# 201100175: - From J. Randolph Babbitt, Administrator: Boeing issued Fleet Team Digest article 737-FTD-27-09002 (enclosure 1) and Service Letter 737-SL-27-I54-G (enclosure 2) to raise awareness of foreign object debris (FOD) in the tailcone area of the 737-300 through -500 series aircraft. Boeing revised the Aircraft Maintenance Manuals (AMM) to add a FOD cautionary and inspection note (enclosure 3). These actions should increase fleet awareness of the issue and enhance maintenance documents to help identify and prevent similar issues. The Federal Aviation Administration is working with Boeing to detem1ine whether airplane modifications are also necessary or if actions already taken to raise awareness are sufficient.
07/13/11	NTSB	201100175	The FAA indicated that it is working with Boeing to determine whether the recommended airplane modifications are necessary. The NTSB welcomes Boeing's actions to increase fleet awareness of foreign object debris in the tailcone area of 737-300 through -500 aircraft as an interim solution. However, we point out that the issuance of advisory documents alone will not satisfy the intent of these recommendations. Accordingly, pending our receipt and review of the FAA's and Boeing's plan for implementing the recommended modifications and requirements, Safety Recommendations A-11-7 through -10 are classified OPEN—ACCEPTABLE RESPONSE.

Recommendation Report

08/21/12	Addressee	201200450	-From Michael P. Huerta, Acting Administrator: The Federal Aviation Administration (FAA) worked with Boeing to evaluate all possible solutions to mitigate the risk of foreign object debris (FOD) that could cause an elevator control system rate jam on 737-300 through -500 series airplanes. A rate jam is a continuous rate command to the actuator valve to extend or retract the actuator. Rate jams can occur in the hydraulic valve with in the actuator and at the external input lever and linkage. We considered design changes, procedural changes, and awareness enhancement as potential mitigations. Potential design enhancements proved to be impractical due to the limited clearance between the tail cone skin and the input crank arm of the left elevator Power Control Unit (PCU). All design solutions, except one, increased the potential risk due to FOD (additional parts or fasteners above the input and assembly), or reduced controllability for other failure conditions. The only design consideration that did not increase risk required a complete redesign of the elevator control system in the aft part of the airplane which was considered impractical. To address the issue through procedural changes, Boeing issued Service Letter 737-SL-27-154, Revision 1-1, which specifies corrosion resistant steel (CRES) bearings as the only option for bearing replacement. Installation drawings, Illustrated Pal15 Catalogs (IPC), and Component Maintenance Manuals (CMM) will reflect the CRES bearing as the only option available when an existing bearing is replaced. Installation of a CRES bearing is expected to decrease the number of subsequent removals required for corrosion and freeplay, resulting in fewer total bearing replacements over the remaining life of the 737-300 through -500 series airplanes. To enhance awareness regarding the risk of FOD in the tail cone area, Boeing issued Fleet Team Digest article 737-FTD-27-09002 and Multi-Operator Message MOM-MOM-09-0357-0 I B. While an elevator rate jam can cause controllability problems as experienced during the Tailwinds event, when making a decision on whether or not to write an Airworthiness Directive (AD), we consider not only the potential adverse outcome but also the probability of occurrence. This isolated event was not caused by a system failure but rather improper maintenance that left FOD in the tail cone of the airplane. Due to the extremely low probability of reoccurrence combined with the mitigating actions already taken this issue docs not reach the threshold for issuance of an AD. The installation of CRES bearings (minimizing future maintenance activity in the tail cone) and documentation changes to enhance awareness to help preclude improper maintenance are appropriate to address the risk. We carefully reviewed the options and determined that a design solution to prevent FOD from entering the input and assembly would increase the risk of creating another rate jam by introducing new parts into the critical area near and above the elevator PCU. Considering the actions Boeing has taken to raise awareness of FOD in the tail cone area of the airplane and the existing uncomplicated input linkage design, we do not believe a design change will decrease the probability of a FOD jam during the remaining fleet life of the 737-300 through -500 series airplanes. Therefore, we do not plan to mandate a design change to protect the elevator PCU input arm assembly on the 737-300 through -500 series airplanes from FOD at this time. We believe that raising awareness regarding the risk of FOD in the tail cone area and provisions for reliably phasing in CRES bearing installation are appropriate to mitigate this risk. I believe that the FAA has effectively addressed these safety recommendations, and I consider our actions complete.

Recommendation Report

01/10/13	NTSB	201200450	The FAA worked with Boeing to evaluate possible solutions to mitigate the risk of FOD causing an elevator control system jam on 737-300 through -500 series airplanes. Potential design modifications proved to be impractical because of the limited clearance between the tailcone skin and the input crank arm of the left elevator Power Control Unit (PCU). All design solutions, except one, either increased the potential risk from FOD because of the presence of additional parts or fasteners above the input arm assembly or reduced controllability for other failure conditions. The only design that did not increase risk required a complete redesign of the elevator control system in the aft part of the airplane, which the FAA considered impractical. The FAA believes that other actions that Boeing has taken, including the installation of corrosion resistant steel bearings (which minimize the need for future maintenance activity in the tailcone) and documentation changes to enhance awareness among mechanics and maintenance organizations of the risk of FOD in the tailcone area, adequately address the risk. We acknowledge the findings of the review by Boeing and the FAA that all design solutions, except one, increase the potential risk due to FOD and that the only other design solution requires such extensive revisions as to be impractical. Consequently, Safety Recommendations A-11-7 and 8 are classified CLOSED—RECONSIDERED.

Recommendation # : A-11-008 **Overall Status:** Closed - Reconsidered **Priority:** CLASS II

TO THE FEDERAL AVIATION ADMINISTRATION: Once Boeing has developed a method to protect the elevator power control unit input arm assembly on 737-300 through -500 series airplanes from foreign object debris as requested in Safety Recommendation A-11-7, require operators to modify their airplanes with this method of protection.

# of Addressees: 1 **Overall Date Closed:** 01/10/13

Addressee: FAA Closed - Reconsidered **Addresee Date Closed:** 01/10/13

04/25/11	Addressee	201100175	CC# 201100175: - From J. Randolph Babbitt, Administrator: Boeing issued Fleet Team Digest article 737-FTD-27-09002 (enclosure 1) and Service Letter 737-SL-27-I54-G (enclosure 2) to raise awareness of foreign object debris (FOD) in the tailcone area of the 737-300 through -500 series aircraft. Boeing revised the Aircraft Maintenance Manuals (AMM) to add a FOD cautionary and inspection note (enclosure 3). These actions should increase fleet awareness of the issue and enhance maintenance documents to help identify and prevent similar issues. The Federal Aviation Administration is working with Boeing to detem1ine whether airplane modifications are also necessary or if actions already taken to raise awareness are sufficient.
07/13/11	NTSB	201100175	The FAA indicated that it is working with Boeing to determine whether the recommended airplane modifications are necessary. The NTSB welcomes Boeing’s actions to increase fleet awareness of foreign object debris in the tailcone area of 737-300 through -500 aircraft as an interim solution. However, we point out that the issuance of advisory documents alone will not satisfy the intent of these recommendations. Accordingly, pending our receipt and review of the FAA’s and Boeing’s plan for implementing the recommended modifications and requirements, Safety Recommendations A-11-7 through -10 are classified OPEN—ACCEPTABLE RESPONSE.

Recommendation Report

08/21/12	Address ee	201200450	-From Michael P. Huerta, Acting Administrator: The Federal Aviation Administration (FAA) worked with Boeing to evaluate all possible solutions to mitigate the risk of foreign object debris (FOD) that could cause an elevator control system rate jam on 737-300 through -500 series airplanes. A rate jam is a continuous rate command to the actuator valve to extend or retract the actuator. Rate jams can occur in the hydraulic valve with in the actuator and at the external input lever and linkage. We considered design changes, procedural changes, and awareness enhancement as potential mitigations. Potential design enhancements proved to be impractical due to the limited clearance between the tail cone skin and the input crank arm of the left elevator Power Control Unit (PCU). All design solutions, except one, increased the potential risk due to FOD (additional parts or fasteners above the input and assembly), or reduced controllability for other failure conditions. The only design consideration that did not increase risk required a complete redesign of the elevator control system in the aft part of the airplane which was considered impractical. To address the issue through procedural changes, Boeing issued Service Letter 737-SL-27-154, Revision 1-1, which specifies corrosion resistant steel (CRES) bearings as the only option for bearing replacement. Installation drawings, Illustrated Pal15 Catalogs (IPC), and Component Maintenance Manuals (CMM) will reflect the CRES bearing as the only option available when an existing bearing is replaced. Installation of a CRES bearing is expected to decrease the number of subsequent removals required for corrosion and freeplay, resulting in fewer total bearing replacements over the remaining life of the 737-300 through -500 series airplanes. To enhance awareness regarding the risk of FOD in the tail cone area, Boeing issued Fleet Team Digest article 737-FTD-27-09002 and Multi-Operator Message MOM-MOM-09-0357-0 I B. While an elevator rate jam can cause controllability problems as experienced during the Tailwinds event, when making a decision on whether or not to write an Airworthiness Directive (AD), we consider not only the potential adverse outcome but also the probability of occurrence. This isolated event was not caused by a system failure but rather improper maintenance that left FOD in the tail cone of the airplane. Due to the extremely low probability of reoccurrence combined with the mitigating actions already taken this issue docs not reach the threshold for issuance of an AD. The installation of CRES bearings (minimizing future maintenance activity in the tail cone) and documentation changes to enhance awareness to help preclude improper maintenance are appropriate to address the risk. We carefully reviewed the options and determined that a design solution to prevent FOD from entering the input and assembly would increase the risk of creating another rate jam by introducing new parts into the critical area near and above the elevator PCU. Considering the actions Boeing has taken to raise awareness of FOD in the tail cone area of the airplane and the existing uncomplicated input linkage design, we do not believe a design change will decrease the probability of a FOD jam during the remaining fleet life of the 737-300 through -500 series airplanes. Therefore, we do not plan to mandate a design change to protect the elevator PCU input arm assembly on the 737-300 through -500 series airplanes from FOD at this time. We believe that raising awareness regarding the risk of FOD in the tail cone area and provisions for reliably phasing in CRES bearing installation are appropriate to mitigate this risk. I believe that the FAA has effectively addressed these safety recommendations, and I consider our actions complete.

Recommendation Report

01/10/13	NTSB	201200450	The FAA worked with Boeing to evaluate possible solutions to mitigate the risk of FOD causing an elevator control system jam on 737-300 through -500 series airplanes. Potential design modifications proved to be impractical because of the limited clearance between the tailcone skin and the input crank arm of the left elevator Power Control Unit (PCU). All design solutions, except one, either increased the potential risk from FOD because of the presence of additional parts or fasteners above the input arm assembly or reduced controllability for other failure conditions. The only design that did not increase risk required a complete redesign of the elevator control system in the aft part of the airplane, which the FAA considered impractical. The FAA believes that other actions that Boeing has taken, including the installation of corrosion resistant steel bearings (which minimize the need for future maintenance activity in the tailcone) and documentation changes to enhance awareness among mechanics and maintenance organizations of the risk of FOD in the tailcone area, adequately address the risk. We acknowledge the findings of the review by Boeing and the FAA that all design solutions, except one, increase the potential risk due to FOD and that the only other design solution requires such extensive revisions as to be impractical. Consequently, Safety Recommendations A-11-7 and 8 are classified CLOSED—RECONSIDERED.

Recommendation # : A-11-009 **Overall Status:** Closed - Reconsidered **Priority:** CLASS II

TO THE FEDERAL AVIATION ADMINISTRATION: Require Boeing to redesign the 737-300 through -500 series airplane elevator control system such that a single-point jam will not restrict the movement of the elevator control system and prevent continued safe flight and landing.

# of Addressees: 1 **Overall Date Closed:** 01/10/13

Addressee: FAA Closed - Reconsidered **Addresee Date Closed:** 01/10/13

04/25/11	Addressee	201100175	CC# 201100175: - From J. Randolph Babbitt, Administrator: Boeing issued Fleet Team Digest article 737-FTD-27-09002 (enclosure 1) and Service Letter 737-SL-27-I54-G (enclosure 2) to raise awareness of foreign object debris (FOD) in the tailcone area of the 737-300 through -500 series aircraft. Boeing revised the Aircraft Maintenance Manuals (AMM) to add a FOD cautionary and inspection note (enclosure 3). These actions should increase fleet awareness of the issue and enhance maintenance documents to help identify and prevent similar issues. The Federal Aviation Administration is working with Boeing to detem1ine whether airplane modifications are also necessary or if actions already taken to raise awareness are sufficient.
07/13/11	NTSB	201100175	The FAA indicated that it is working with Boeing to determine whether the recommended airplane modifications are necessary. The NTSB welcomes Boeing's actions to increase fleet awareness of foreign object debris in the tailcone area of 737-300 through -500 aircraft as an interim solution. However, we point out that the issuance of advisory documents alone will not satisfy the intent of these recommendations. Accordingly, pending our receipt and review of the FAA's and Boeing's plan for implementing the recommended modifications and requirements, Safety Recommendations A-11-7 through -10 are classified OPEN—ACCEPTABLE RESPONSE.

Recommendation Report

08/21/12	Address ee	201200450	-From Michael P. Huerta, Acting Administrator: The FAA worked with Boeing to evaluate potential design changes to add a break out device to isolate a jam in either the left or right side of the elevator system that would not degrade controllability during operation with failures. The 737 remains controllable in manual reversion mode in the event of a dual hydraulic system failure. In manual reversion, the pilots have direct control of the elevator surfaces since the forces applied to the column arc directly connected to the elevators through de-pressurized moving body actuators. This system requires that both left and right elevator surfaces be hard tied together through the upper torque tube to ensure symmetric surface movement. We concluded that a break out device designed to isolate either a left or right jammed elevator would result in the operating elevator imparting significant and unacceptable torsion loads to the airplane fuselage structure requiring significant changes to the a airframe structure and recertification of the elevator control system. As such, adding a break out device is not warranted. We have reviewed findings from all reports of jammed or restricted elevator controls. In all circumstances for which flight data recorder (FOR) data was available, the results showed that the pilot column force levels were not considered excessive and were well within the capability of the flying pilot. Therefore, the issue does not meet the criteria for issuance of an Airworthiness Directive (AD). Design standards and practices in critical locations, such as pulley and cable guards, are utilized throughout the flight control systems to specifically prohibit foreign objects from contacting and/or jamming the systems. However, we assessed system redesign options to further mitigate the effects of a position jam. There is no technically feasible design that could be incorporated into the design envelope that would not significant ly impact the reliability of the system and the overall product. A redesign of the elevator control system to prevent any single-point jam from restricting movement of the elevator control system on the 737-300 through -500 series airplanes is not feasible. I believe that the FAA has effectively addressed these safety recommendations, and I consider our actions complete.
01/10/13	NTSB	201200450	The FAA and Boeing evaluated potential design changes to add a breakout device to isolate a jam in either the left or right side of the elevator system and found that such a breakout device would result in significant and unacceptable torsion loads to the airplane fuselage structure, requiring significant changes and recertification of the elevator control system. As a result, the FAA concluded that adding a breakout device is not advisable. The FAA also assessed system redesign options to mitigate the effects of a position jam but concluded that there is no technically feasible design that would not adversely impact the reliability of the system. Therefore, the FAA believes that a redesign of the elevator control system to prevent any single point jam from restricting movement of the elevator control system on the 737-300 through -500 series airplanes is not feasible. We reviewed the information the FAA provided and agree that the recommended redesign of the system on these airplanes is not feasible; consequently, Safety Recommendations A-11-9 and -10 are classified CLOSED—RECONSIDERED.

Recommendation Report

Recommendation # : A-11-010 **Overall Status:** Closed - Reconsidered **Priority:** CLASS II

TO THE FEDERAL AVIATION ADMINISTRATION: Once the 737-300 through -500 series airplane elevator control system is redesigned as requested in Safety Recommendation A-11-9, require operators to implement the new design.

# of Addressees: 1 **Overall Date Closed:** 01/10/13

Addressee: FAA Closed - Reconsidered **Addresee Date Closed:** 01/10/13

04/25/11	Addressee	201100175	CC# 201100175: - From J. Randolph Babbitt, Administrator: Boeing issued Fleet Team Digest article 737-FTD-27-09002 (enclosure 1) and Service Letter 737-SL-27-I54-G (enclosure 2) to raise awareness of foreign object debris (FOD) in the tailcone area of the 737-300 through -500 series aircraft. Boeing revised the Aircraft Maintenance Manuals (AMM) to add a FOD cautionary and inspection note (enclosure 3). These actions should increase fleet awareness of the issue and enhance maintenance documents to help identify and prevent similar issues. The Federal Aviation Administration is working with Boeing to detem1ine whether airplane modifications are also necessary or if actions already taken to raise awareness are sufficient.
07/13/11	NTSB	201100175	The FAA indicated that it is working with Boeing to determine whether the recommended airplane modifications are necessary. The NTSB welcomes Boeing's actions to increase fleet awareness of foreign object debris in the tailcone area of 737-300 through -500 aircraft as an interim solution. However, we point out that the issuance of advisory documents alone will not satisfy the intent of these recommendations. Accordingly, pending our receipt and review of the FAA's and Boeing's plan for implementing the recommended modifications and requirements, Safety Recommendations A-11-7 through -10 are classified OPEN—ACCEPTABLE RESPONSE.
08/21/12	Addressee	201200450	-From Michael P. Huerta, Acting Administrator: The FAA worked with Boeing to evaluate potential design changes to add a break out device to isolate a jam in either the left or right side of the elevator system that would not degrade controllability during operation with failures. The 737 remains controllable in manual reversion mode in the event of a dual hydraulic system failure. In manual reversion, the pilots have direct control of the elevator surfaces since the forces applied to the column arc directly connected to the elevators through de-pressurized moving body actuators. This system requires that both left and right elevator surfaces be hard tied together through the upper torque tube to ensure symmetric surface movement. We concluded that a break out device designed to isolate either a left or right jammed elevator would result in the operating elevator imparting significant and unacceptable torsion loads to the airplane fuselage structure requiring significant changes to the a airframe structure and recertification of the elevator control system. As such, adding a break out device is not warranted. We have reviewed findings from all reports of jammed or restricted elevator controls. In all circumstances for which flight data recorder (FOR) data was available, the results showed that the pilot column force levels were not considered excessive and were well within the capability of the flying pilot. Therefore, the issue does not meet the criteria for issuance of an Airworthiness Directive (AD). Design standards and practices in critical locations, such as pulley and cable guards, are utilized throughout the flight control systems to specifically prohibit foreign objects from contacting and/or jamming the systems. However, we assessed system redesign options to further mitigate the effects of a position jam. There is no technically feasible design that could be incorporated into the design envelope that would not significant ly impact the reliability of the system and the overall product. A redesign of the elevator control system to prevent any single-point jam from restricting movement of the elevator control system on the 737-300 through -500 series airplanes is not feasible. I believe that the FAA has effectively addressed these safety recommendations, and I consider our actions complete.

Recommendation Report

01/10/13	NTSB	201200450	The FAA and Boeing evaluated potential design changes to add a breakout device to isolate a jam in either the left or right side of the elevator system and found that such a breakout device would result in significant and unacceptable torsion loads to the airplane fuselage structure, requiring significant changes and recertification of the elevator control system. As a result, the FAA concluded that adding a breakout device is not advisable. The FAA also assessed system redesign options to mitigate the effects of a position jam but concluded that there is no technically feasible design that would not adversely impact the reliability of the system. Therefore, the FAA believes that a redesign of the elevator control system to prevent any single point jam from restricting movement of the elevator control system on the 737-300 through -500 series airplanes is not feasible. We reviewed the information the FAA provided and agree that the recommended redesign of the system on these airplanes is not feasible; consequently, Safety Recommendations A-11-9 and -10 are classified CLOSED—RECONSIDERED.

Recommendation # : A-11-011 **Overall Status:** Closed - Unacceptable Action **Priority:** CLASS II

TO THE FEDERAL AVIATION ADMINISTRATION: Require Boeing to develop recovery strategies (for example, checklists, procedures, or memory items) for pilots of 737 airplanes that do not have a mechanical override feature for a jammed elevator in the event of a full control deflection of the elevator system and incorporate those strategies into pilot guidance. Within those recovery strategies, the consequences of removing all hydraulic power to the airplane as a response to any uncommanded control surface should be clarified.

# of Addressees: 1 **Overall Date Closed:** 03/27/14

Addressee: FAA Closed - Unacceptable Action **Addresee Date Closed:** 03/27/14

04/25/11	Addressee	201100175	CC# 201100175: - From J. Randolph Babbitt, Administrator: We are working with Boeing to review and evaluate 737 recovery strategies in response to any detected uncomn1anded control surface movement. I will keep the Board informed of the progress of these safety recommendations and provide an updated response to these recommendations by June 2012.
07/13/11	NTSB	201100175	The NTSB notes that the FAA is working with Boeing to review and evaluate recovery strategies in response to any detected uncommanded control surface movement of 737 airplanes. Pending our receipt and review of the FAA's June 2012 update on its progress, Safety Recommendation A-11-11 is classified OPEN—ACCEPTABLE RESPONSE.

Recommendation Report

08/21/12	Address ee	201200450	-From Michael P. Huerta, Acting Administrator: Since 1991, all 737 Quick Reference Handbook (QRI-I) Non-Normal Procedures (NNP) have contained a section of jammed or restricted flight controls. For a jammed elevator, the guidance is to apply maximum pilot effort (including both pilots, if necessary) in order to free the obstruction. In addition, this guidance also includes a step not to turn off any flight control switches, which would remove hydraulic power. This checklist is intended to provide guidance for many restrictions or jam scenarios including the one experienced by the Tailwind Airlines flight crew. The potential negative consequences of not following checklists are typically not included in either the checklist or the training material. This is primarily because there are a variety of scenarios associated with a specific action. For example, prior to selecting the flight control switches off, removing hydraulic power to the flight controls, the Tailwind Airlines flight crew had trimmed the horizontal stabilizer to its maximum airplane nose down position. By removing the hydraulic power to the elevator system, the surfaces began to fair with the stabilizer creating a significant airplane nose down response at very low altitude. The crew quickly restored hydraulic power in order to regain some control over the flight path. We believe that the current checklist provides succinct and correct procedures for jammed or restricted flight controls and is sufficient to mitigate the risk of low-frequency, NNP procedures. We understand the desire to provide information to the flight crew regarding the consequences of removing all hydraulic power to the airplane as a response to any uncommanded control surface movement but we do not agree that this information should be incorporated into the QRH NNP. Recurrent training is appropriately designed to address more likely scenarios. We believe that adding the consequences of inappropriate crew actions may negatively affect crew progress in accomplishing the checklist and should be avoided. I believe that the FAA has effectively addressed these safety recommendations, and I consider our actions complete.

Recommendation Report

01/10/13	NTSB	201200450	The FAA replied that the Quick Reference Handbook (QRH) for the Boeing 737 already contains a section about jammed or restricted flight controls. In addition, the FAA stated its opposition to the recommended addition of a warning not to turn off hydraulic power because the potential negative consequences that can result from not following checklists (turning off hydraulic power is not an indicated action in the QRH for jammed or restricted flight controls) are typically not included in either the checklist or the training material. The FAA believes that the current checklist provides succinct and correct procedures for addressing jammed or restricted flight controls and is sufficient, and the FAA does not plan to take any further action in response to this recommendation. Although in the Tailwinds flight OHY036 incident the flight crew was unable to consult the QRH, the crew took the actions specified in the handbook and was able to stabilize the situation. They encountered difficulty only when they attempted to improvise a solution to their problem outside the procedure outlined in the QRH, likely because they had not received any training or instruction about the dangers associated with loss of hydraulics and the lack of a mechanical override. The intent of this recommendation is for a note to be added in the QRH, or other appropriate document such as the flight crew operating manual (FCOM), advising flight crews encountering jammed or restricted flight controls not to attempt to clear the problem by turning off the hydraulics. We acknowledge the FAA's concern about the negative training aspect of the QRH's directing flight crews not to take a particular action, but we continue to believe that guidance is needed to warn crews about the danger of turning off the hydraulics. To choose not to include such a warning, as the FAA intends, means that other crews will also be left unaware of the potential danger, leaving them as unprepared as the crew of the Tailwinds flight OHY036 should they confront a similar problem, thus increasing the likelihood of a similar accident in the future. Before closing this recommendation, we ask the FAA to consider other possible actions, such as issuing guidance via a safety alert for operators or an information for operators bulletin targeting operators of these aircraft. Such guidance would provide details of this investigation and the dangers of removing hydraulics to clear a jam, a procedure not outlined in the QRH. Pending the FAA's reconsideration of its position and taking such action, Safety Recommendation A-11-11 is classified OPEN—UNACCEPTABLE RESPONSE.

Recommendation Report

02/20/14	Addressee	201400199	-From Michael P. Huerta, Administrator: In its January 10, 2013, letter, the Board asked the Federal Aviation Administration (FAA) to consider issuing a Safety Alert for Operators (SAFO) or other guidance to provide details of the Tailwinds flight OHY036 investigation and to highlight to operators the danger of removing hydraulic power in the event of a flight control jam. To address the Board’s request, we reviewed training programs, current infom1ation bulletins, and the Quick Reference Handbook (QRH), and we evaluated options for informing operators. We also surveyed U.S. operators about flight control system jam training. The QRH Non-Normal Checklists (NNC) includes recommended flightcrew procedures to address abnormal airplane conditions. The Jammed or Restricted Flight Controls NNC is intended to be followed in the event of any flight control jam or restriction, including the type of event experienced by the Tailwinds crew. The QRH Jammed or Restricted Flight Controls NNC procedure is to apply maximum pilot effort (including both pilots, if necessary) in order to free the obstruction. The NNC also specifically cautions the crew to not turn off any flight control switches. As noted by the Board, the Tailwinds flightcrew, without consulting the QRH, followed the appropriate QRH Jammed or Restricted Flight Controls NNC procedures up until the time they turned off the flight control switches. Turning off the flight control switches removes hydraulic power from the flight controls and activates the standby rudder actuator. This action is only to be taken in the event of three specific abnormal conditions unrelated to a pitch axis flight control jam or restriction. The Boeing Flight Crew Training Manual (rCTM) instructs the crew to, in the event of a control system jam, apply maximum force to clear the jam, and to use stabilizer and/or rudder trim to offload control forces. The chapter about "troubleshooting" and jammed control flying, states, "In case of jammed flight controls, do not attempt troubleshooting beyond the actions directed in the NNC unless the airplane cannot be safely landed with the existing condition. Always comply with NNC actions to the extent possible.'• We also evaluated U.S. operator training programs that address airplane upsets and flight control system jams. There are 246 affected aircraft that are operated in the United States including Boeing 737-200 through -500 models. Southwest, US Airways, and Alaska Airlines account for almost 200 of those 246 planes. We found that all U.S. operators train for jammed controls during both initial training and as part of recurrent upset training. We confirmed that none of these training programs instruct the crew to turn off the flight control switches in response to a jam or obstruction in the flight control system. The Board also noted in its last response that the Tailwinds flightcrew was unable to consult the QRH clue to the immediate nature of the event. In such instances the crew has to rely on training and fly the airplane with whatever force is needed to keep control and consult the QRH when safe to do so. Based on our findings, we believe the QRH guidance and the current training are appropriate to address the issue. In addition, we believe that issuance of an Information for Operators or SAFO would not benefit operators above the information that is already provided through existing procedural guidance and training. U.S. operators have already included the Boeing FCTM control system jam sections in their training programs. The same FCTM is provided to all operators or the aircraft worldwide. We continue to believe that additional guidance describing the potential negative consequences of not following checklists would have little, if any, benefit in addressing the possible negative outcomes linked to not following the Jammed or Restricted Flight Controls NNC or other checklists. Rather, we will continue to emphasize appropriate training and procedures that lead to a safe resolution of abnormal conditions. I believe that the FAA has effectively addressed these recommendations, and I consider our actions complete.

Recommendation Report

03/27/14	NTSB	201400199	You previously told us that the Quick Reference Handbook (QRH) for the Boeing 737 already contains a section about jammed or restricted flight controls, and that you believe that the current checklist provides succinct and correct procedures. You stated that you did not plan to take any further action in response to this recommendation. In addition, you opposed the recommended addition of a warning not to turn off hydraulic power, because the potential negative consequences that can result from not following checklists (turning off hydraulic power is not an indicated action in the QRH for jammed or restricted flight controls) are typically not included either on the checklist or in the training material. We note, however, that warnings are included in the Boeing QRH, and Boeing defines a warning in the QRH as “an operating procedure, technique, etc., that may result in personal injury or loss of life if not carefully followed.” In our January 13, 2013, letter about this recommendation, we asked you to reconsider your opposition. The flightcrew in the Tailwinds flight OHY036 incident took the actions specified in the QRH handbook and were able to stabilize the situation. They encountered difficulty only when they attempted to improvise a solution to their problem outside the procedure outlined in the QRH, likely because they had not received any training or instruction about the dangers associated with loss of hydraulics and the lack of a mechanical override. We reiterated that the intent of this recommendation was for some type of notice to flightcrews advising that, if they encounter jammed or restricted flight controls, they should not attempt to clear the problem by turning off the hydraulics. We stated that your decision not to include such a warning would leave other crews equally unaware of the potential danger and, therefore, as unprepared as the crew of the Tailwinds flight OHY036, should they confront a similar problem. We asked you to consider issuing guidance via a safety alert for operators (SAFO) or an information for operators bulletin (InFO) that would provide details of our investigation and the dangers of removing hydraulics to clear a jam, a procedure not outlined in the QRH. We note that you reviewed training programs, current information bulletins, and the QRH in response to our request for your reconsideration. You also surveyed US operators about flight control system jam training, yet you remain opposed to the recommendation because you still believe that the QRH guidance and the current training are appropriate to address the issue, and that issuance of an InFO or SAFO would not provide any additional benefit to operators. We disagree with you. We continue to believe in the benefit of providing flightcrews with details about our investigation and the dangers of removing hydraulics to clear a jam. However, because you have made clear that you will take no further action to address Safety Recommendation A 11 11, it is classified CLOSED—UNACCEPTABLE ACTION.

Recommendation Report

Total Number of Recommendations for Recommendation Report: 5

Servisair

ATTN: [redacted], OTKES

Sender:

[redacted], Quality Manager
Servisair Finland Oy
Rahtikuja 1
01530 VANTAA

DE-ICING PROCESS OF DY5630 26.12.2012

In accordance with your request of de-icing data regarding flight NAX5630 on 26.12.2012 we are providing you the following information.

No discrepancies were reported during de-icing process. Weather was normal winter conditions with temperature -16 degrees celsius .

Aircraft LN-DYM arrived to EFHK 23.12.2012 21:27 from EFOU and had a lenghty lay-over in EFHK due to holiday season. It departed for Kittilä on 26.12.2012 8:45 local Helsinki time.

Aircraft taxied for de-icing to EFHK apron 8 for de-icing, allocated by Finavia de-icing coordinator.

Servisair Finland Oy is contracted de-icing operator for Norwegian Air Shuttle in Helsinki and aircraft was sprayed with 3 trucks, internal numbers D2, D7 and D8.

Truck D2 is finnish made unit, manufactured by Kiitokori Oy in Kausala, Finland. D7 and D8 are Vestergaard AS manufactured units and taken into service 12/2012.

De-icing process was started 8:58 local time and ended 9:13 local time. Aircraft was treated with type I fluid (manufacturer Clariant, brandname Safewing MP 1 1938 ECO (80), wings, stabilizers and fuselage. Propotional mixture of 30-60% glycol was used (ice melting 30% and final application 60%)

Water 1807 litres, Type I 1136 litres were used

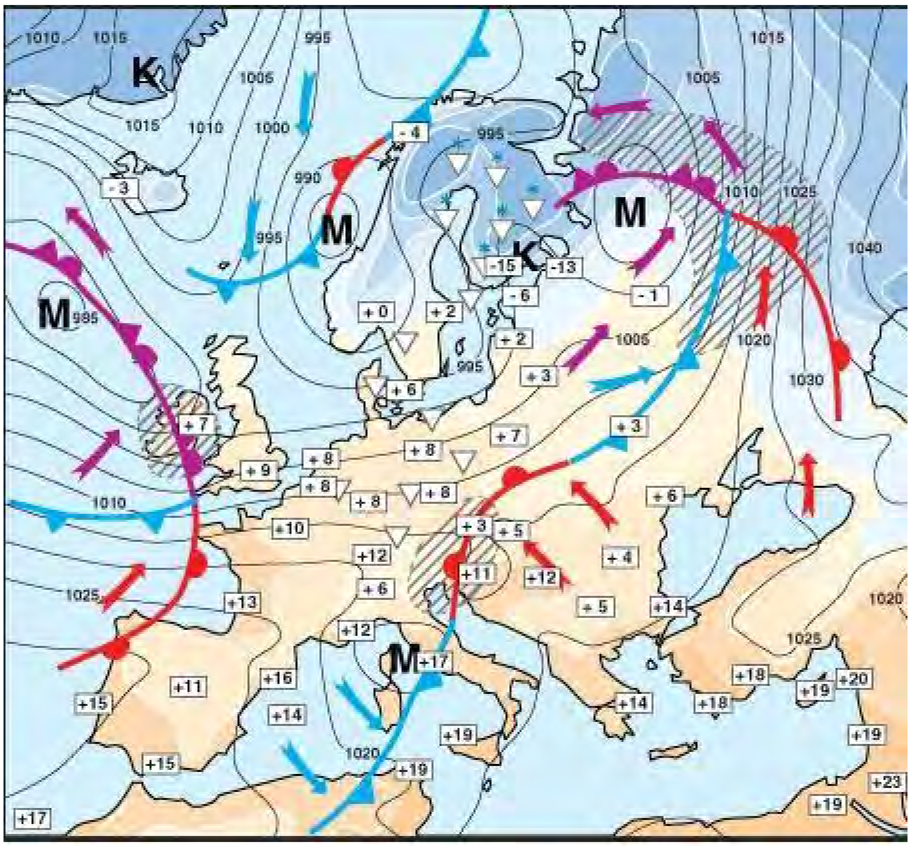
All operators involved in process have long background of de-icing, and one of them a instructor.

Aircraft was icy due to long ground time and heavy snow accumulation (see weather data on separate spreadsheet). After de-icing aircraft was released to TWR freq 118.6 normally.

ILMATIETEEN LAITOS Aviation and Military Weather Service Author: Matti Heinonen	Estimate about weather situation at Kittilä aeroport 26.12.2012 at 08.30 UTC Dnro 5/420/2013		
		Date 22.1.2013	

1. Synoptical weather situation

Ridge of high extending from Baltic States to Finland, and cold airmass over Finland and Northern Scandinavia and locally light snowfall. Winds are weak.



Picture 1. Finnish Meteorological Institute's weather analyze at 12 UTC 26.12.2012.

2. Weather parameters

2.1.Wind conditions

Near the ground 10 minute's average wind has been variable and average wind velocity less than two knots.

Higher in atmosphere between 1000 feet(ft) and 5000ft wind direction were mostly between 320-010 degrees and wind velocity fluctuated between 5 and 15 knots. Wind maximum was about 20 knots height 2500ft around 9 UTC. These values are based on Laps model. Laps is data assimilation system bringing a variety of datasets into numerical models for the production of very detailed analyses of local weather condition and short-range forecasts. The data consists of surface observing systems, radars, satellites, wind and temperature profiles as well as sounding profiles. This day 26.12. Sodankylä sounding 00 UTC is out of data and that's why the profiles have estimated from other datasets and Laps. In Northern Scandinavia we have only Lulea sounding 00 UTC from Sweden, and later 12 UTC sounding data from Sodankylä is available.

Wind shear is a difference in wind speed and direction over a relatively short distance in the atmosphere. The shear will usually express knots against 100 feet. Based on the International Civil Aviation Organization (ICAO) wind shear is:

Normal if change is 0-4 kt/100ft
Moderate if change is 5-8kt/100ft
Strong if change is 9-12kt/100ft
Severe if change is over 12kt/100ft

Table 1. Kittilä wind profile 26.12.2012 at 08 and 09 UTC based on Laps.

time	08 UTC		09 UTC	
height/ft	Wind direction	velocity/kt	Wind direction	velocity /kt
1000	280°	2	320°	2
1700	320°	5	320°	5
2200	350°	8	010°	9
2500	020°	12	050°	20
3100	360°	11	010°	12
4000	010°	13	010°	13
5500	360°	13	010°	10

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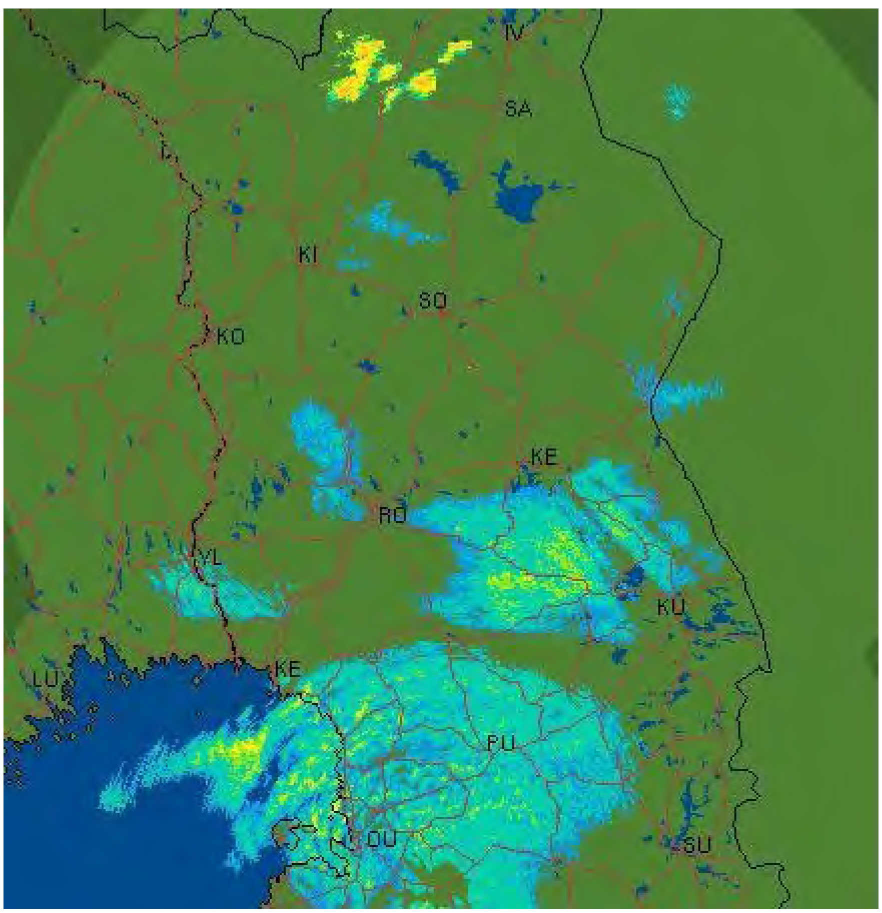
In Kittilä case, 26.12.2012 should wind shear be normal based on Laps, maybe some below height 3000ft it might be temporarily moderate.

2.2 Visibility

Based on metar's, visibility were 10 kilometers or over between 7 and 9 UTC.

2.3 Weather phenomena

Based on metar's and radar it was dry weather in Kittilä. Picture 2 shows radar picture at time 08.30 UTC. It seems some light snowfall towards northeast from Kittilä (KI) and also towards south near Ro that is city of Rovaniemi.



Picture 2. Radar picture 26.12.2012 at 08.30UTC.

2.4 Cloudiness

There were first almost clear skies in Kittilä. Before 6 UTC it began form stratocumulus(sc) clouds whose cloud base were around 2500ft based on metar's and that sc-cloudiness became already overcast in 06.20 UTC metar.

2.5 Temperature

Temperature on the ground was about minus 20 degrees and there were a strong inversion near the ground which can be seen from Laps, picture 4. Also sounding from Lulea 00 UTC picture 3 indicates strong inversion in Northern Scandinavia. In Finland we have Sodankylä sounding at 12 UTC, picture 5. There can still be seen inversion level below one kilometer. An another inversion level is around 5000ft in Sodankylä 12 UTC it's anymore about 5 degrees, but earlier pilot report (Boeing 737) has noticed there 11 degrees inversion at 0911UTC.

3 Weather forecasts and reports

Gafor-forecast for Northern Finland areas 30/39 (Kittilä belongs to area number 36) valid 26.12.2012 between 03 and 12 UTC.

KHY013 260145
GG EFHKFBPS EFCCYMYX
260200 EFHKYBYU
FBFI43 EFRO 260200
GA-FCST FOR AREAS 30/39 VALID 0312
WX ALAPILVISYYTTÄ VAIHTELEVALLA
ALARAJALLA. ETELÄSSÄ JA YLÄ-LAPISSA
PAIKOIN SELKEÄÄ. NÄKYVYYTTÄ HEIKENTÄÄ
PAIKOIN LUMISADE TAI JÄÄNEULASET.
POHJOISOSASSA INVERSIO 10-15 ASTETTA.
WINDS 30/32............33/39
SFC 330-050/01-03KT..300-030/02-07KT
2000FT VRB/02-05KT......270-360/10-25KT
5000FT 330-040/02-13KT..290-010/05-15KT
0-LEVEL NIL
ICE NIL

ILMATIETEEN LAITOS Aviation and Military Weather Service Author: Matti Heinonen	Estimate about weather situation at Kittilä aeroport 26.12.2012 at 08.30 UTC Dnro 5/420/2013	
	Date 22.1.2013	

TURB NIL
GAFOR EFRO 0312 BBBB 30,31,33,38,39 O
32,33,34/37 O LCA M/X ST,SN,IC=

Gafor-forecast for Northern Finland areas 30/39 has amendent at 08.33 UTC:

KHY103 260833
GG EFHKFBPS EFCCYMYX
260200 EFHKYBYU
FBFI43 EFRO 260200 AAA
GA-FCST FOR AREAS 30/39 VALID 0812
WX ALAPILVISYYTTÄ VAIHTELEVALLA
ALARAJALLA. ETELÄSSÄ JA YLÄ-LAPISSA
PAIKOIN SELKEÄÄ. NÄKYVYYTTÄ HEIKENTÄÄ
PAIKOIN LUMISADE TAI JÄÄNEULASET.
POHJOISOSASSA INVERSIO 10-15 ASTETTA.
WINDS 30/32............33/39
SFC 330-050/01-03KT..300-030/02-07KT
2000FT VRB/02-05KT......270-360/10-25KT
5000FT 330-040/02-13KT..290-010/05-15KT
0-LEVEL NIL
ICE NIL
TURB NIL
GAFOR EFRO 0812 BBBB 30/33,35,38,39 O/D
LCA M SN 34,36,37 O/D LCA X ST/BR/SN=

Weather report wrep from Kittilä aeroport at 09.11 UTC:

KHY117 260911
GG EFHKWXFI
260911 EFKTZTZX
UAFI31 EFKT 260911
WXREP
B737 REP INV M11 DEG AT 5000FT EFKT TMA =

ILMATIETEEN LAITOS Aviation and Military Weather Service Author: Matti Heinonen	Estimate about weather situation at Kittilä aeroport 26.12.2012 at 08.30 UTC Dnro 5/420/2013		
		Date 22.1.2013	

Metar reports at Kittilä aeroport:

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METAR EFKT 260520Z AUTO 33001KT 9999 FEW003 M30/M33 Q0991=

METAR EFKT 260550Z AUTO 24001KT 9999 BR FEW001 SCT036 M29/M32
      Q0991=

METAR EFKT 260620Z AUTO 30001KT 2400 BR OVC030 M26/M29 Q0991=

METAR EFKT 260650Z AUTO 00000KT 9999 OVC029 M25/M27 Q0991=

METAR EFKT 260720Z 00000KT 9999 OVC028 M23/M25 Q0991 34490595=

METAR EFKT 260750Z 00000KT 9999 OVC025 M22/M24 Q0992 34490154=

METAR EFKT 260820Z 00000KT 9999 OVC025 M21/M24 Q0992 34490154=

METAR EFKT 260850Z 00000KT 9999 OVC025 M21/M23 Q0992 34490154=

METAR EFKT 260920Z 00000KT 9999 OVC024 M20/M22 Q0993 34490154=
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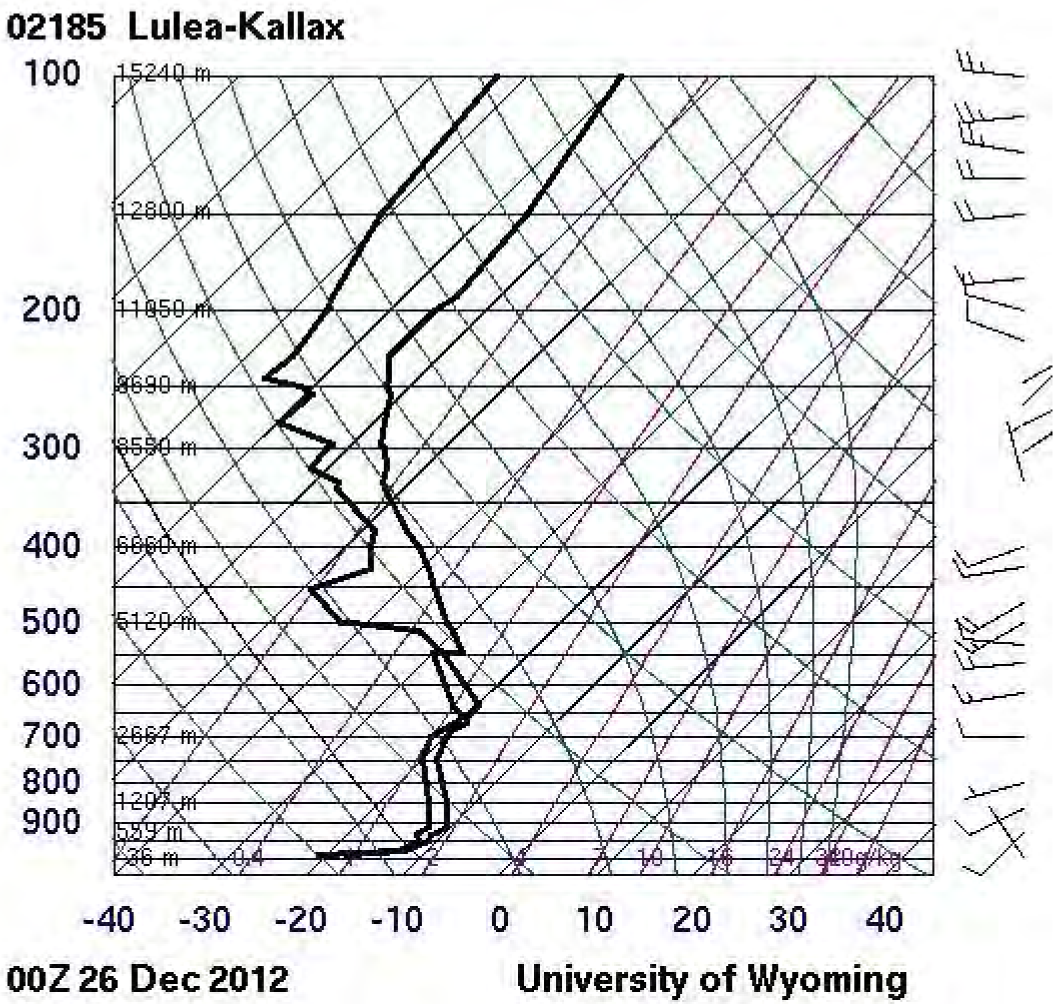
And aerodrome forecast valid 26.12.2012 between 06Z and 15Z:
TAF EFKT 260527Z 2606/2615 03002KT 9999 FEW007 TEMPO 2606/2609 6000 IC BECMG 2612/2614 BKN008=

ILMATIETEEN LAITOS Aviation and Military Weather Service	Estimate about weather situation at Kittilä aeroport 26.12.2012 at 08.30 UTC Dnro 5/420/2013		
Author:		Date	
Matti Heinonen		22.1.2013	



Picture 3. Lulea sounding at 00UTC 26.12.2012 is taken from website: http://weather.uwyo.edu/upperair/sounding.html

ILMATIETEEN LAITOS Aviation and Military Weather Service Author: Matti Heinonen	Estimate about weather situation at Kittilä aeroport 26.12.2012 at 08.30 UTC Dnro 5/420/2013		
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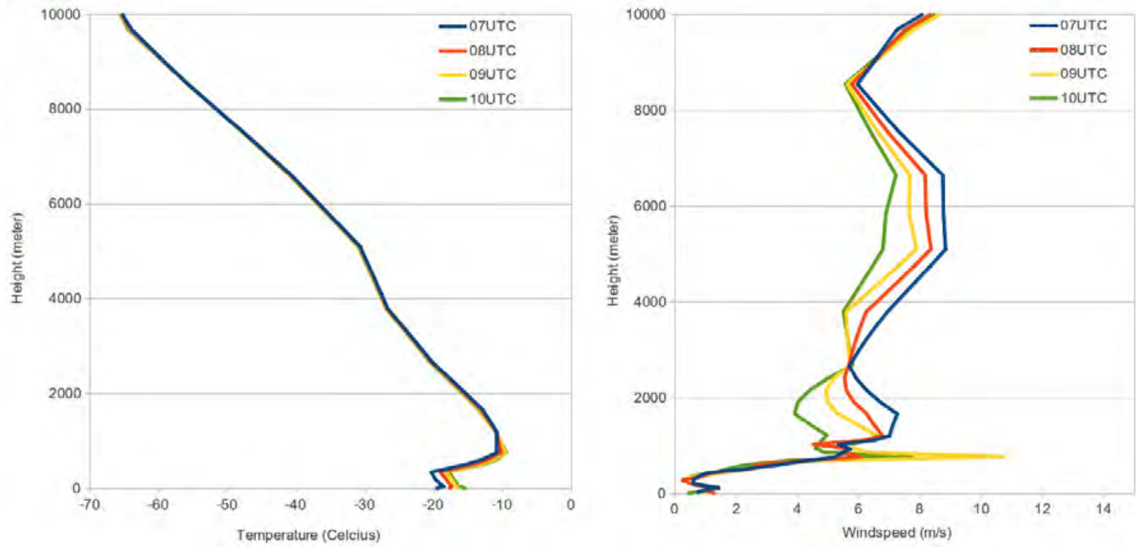

Picture 4. Laps analyze about temperature (on the left) and wind speed (on the right) profiles in Kittilä. Blue colour shows how model has seen the situatition at 07UTC, red 08UTC, yellow 09UTC and green 10UTC.

ILMATIETEEN LAITOS Aviation and Military Weather Service Author: Matti Heinonen	Estimate about weather situation at Kittilä aeroport 26.12.2012 at 08.30 UTC Dnro 5/420/2013		
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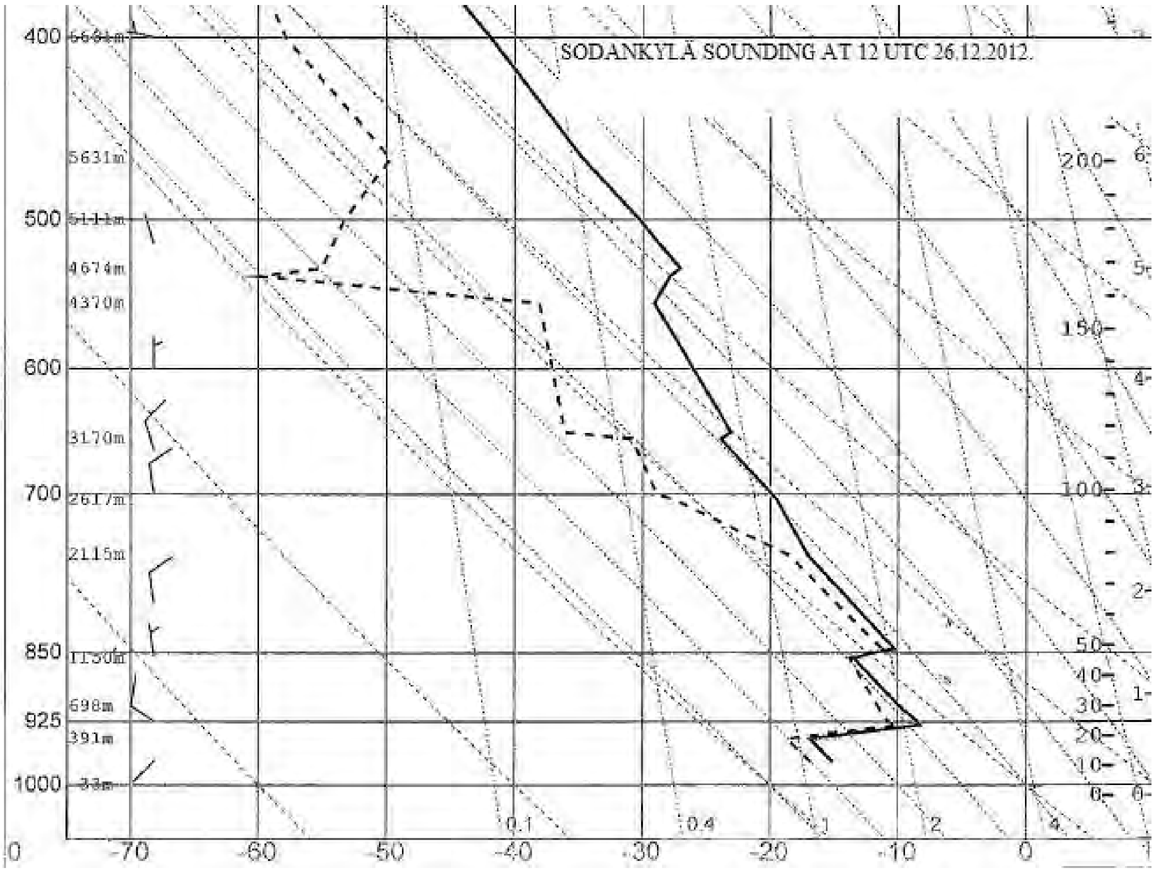
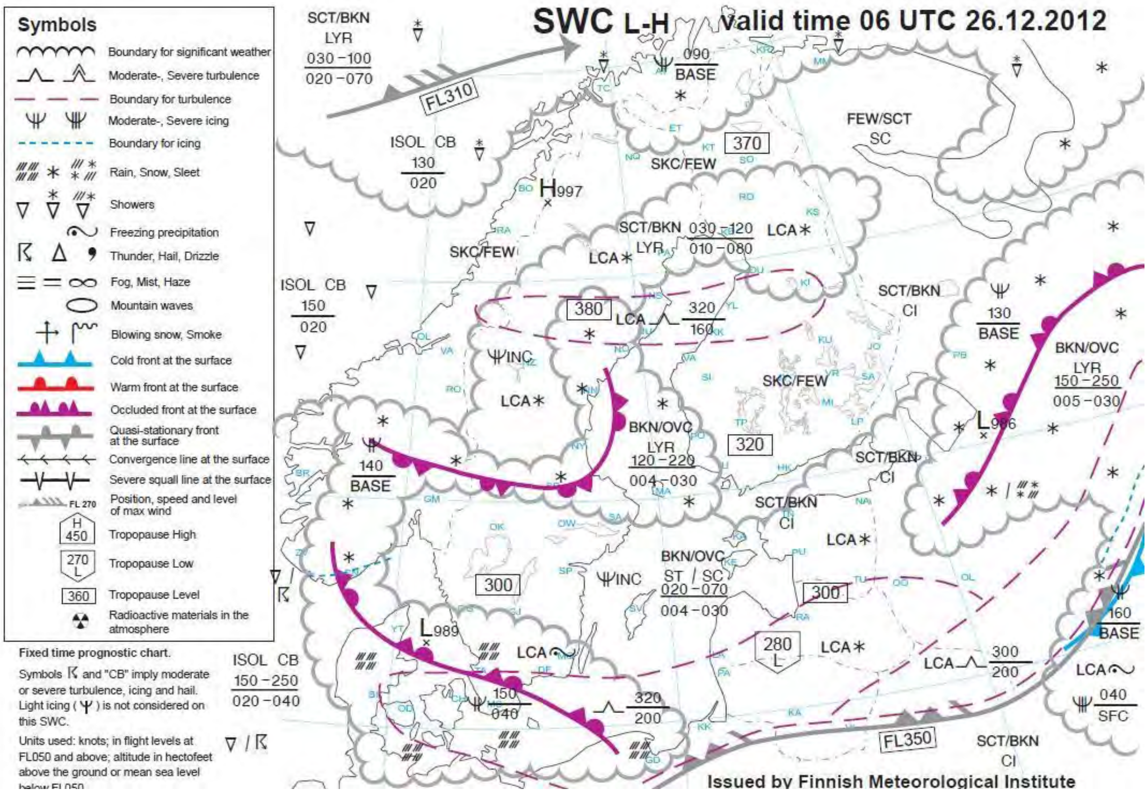


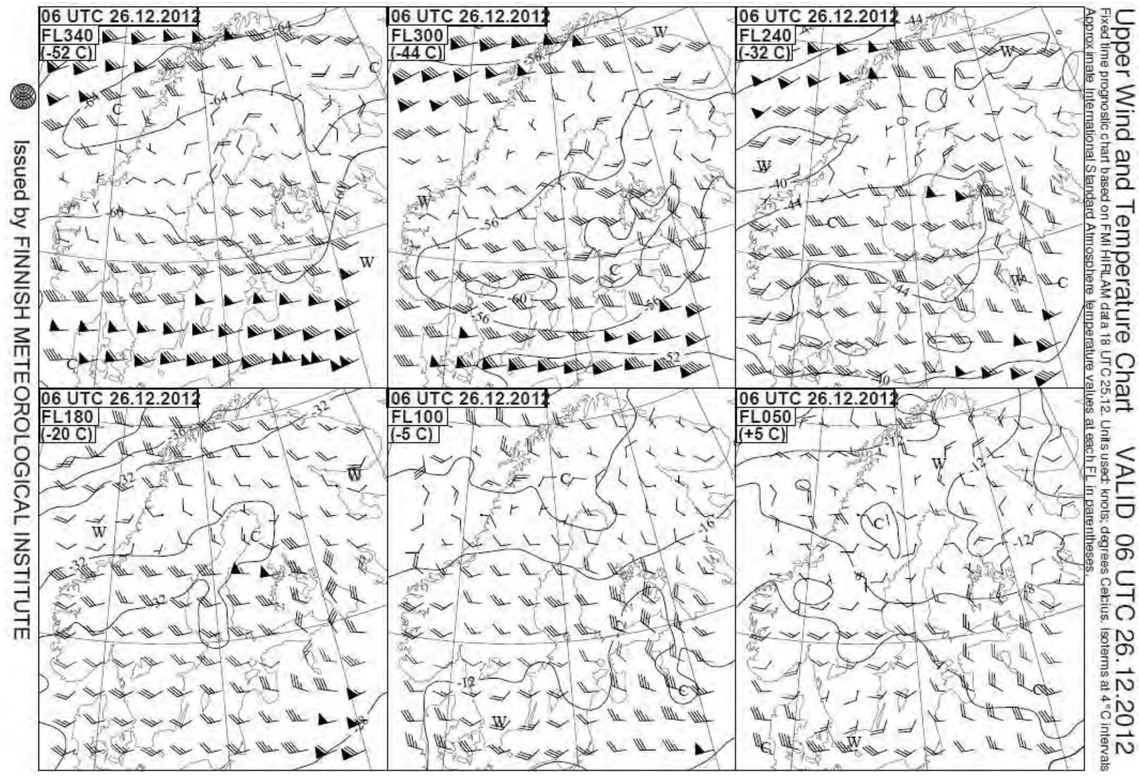
Picture 5. Sodankylä sounding at 12UTC 26.12.2012.

ILMATIETEEN LAITOS Aviation and Military Weather Service	Estimate about weather situation at Kittilä aeroport 26.12.2012 at 08.30 UTC Dnro 5/420/2013		
Author: Matti Heinonen		Date 22.1.2013	



Picture 6. Scandinavian significant weather chart 06UTC 26.12.2012 made by FMI.

ILMATIETEEN LAITOS Aviation and Military Weather Service	Estimate about weather situation at Kittilä aeroport 26.12.2012 at 08.30 UTC Dnro 5/420/2013	
Author:		Date
Matti Heinonen		22.1.2013



Picture 7. Upper wind and temperature chart over Skandinavia based on FMI Hirlam model date run 18UTC 25.12.2012. Chart is valid 06UTC 26.12.2012.

4 Summary

It was dry weather in Kittilä 26.12.2012 between 8 and 9 UTC and visibility was good. Sc-cloud base was at 2500 feet and below that cloud cover there was a strong inversion. An another inversion of about 10 degrees was noticed in height of 5000 feet. No other remarkable weather phenomenas has not been noticed.