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Swiss Transportation Safety Investigation Board STSB

Aviation Division

Final Report No. 2245 by the Swiss Transportation Safety Investigation Board STSB

concerning the accident involving the Bombardier DHC-8-402 aircraft, registration 9A-CQC,

operated by Croatia Airlines under flight plan call sign CTN 464

on 27 September 2013

on runway 14 of Zurich Airport

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Ursachen

Der Unfall ist darauf zurückzuführen, dass die Flugbesatzung das Bugfahrwerk nicht ausfahren konnte und in der Folge eine Landung mit ausgefahrenem Hauptfahrwerk und eingefahrenem Bugfahrwerk durchführen musste.

Als direkte Ursache dieses Unfalls wurde folgender Faktor ermittelt:

- Die WOW *cover plate* des Bugfahrwerks war an beiden unteren Haltevorrichtungen gebrochen, sodass sie um die oberen Befestigungs-punkte nach oben gebogen und im Mechanismus des Bugfahrwerks eingeklemmt wurde, was das Ausfahren verhinderte.

Der Bruch der unteren Haltevorrichtungen der WOW *cover plate* konnte auf folgende Faktoren zurückgeführt werden:

- Die Art der Befestigung der WOW *cover plate* führte bei Betätigen der Bugradsteuerung zu einer lateralen Krafteinwirkung auf die WOW *cover plate* und so zu einer mechanischen Belastung im Bereich der oberen und unteren Haltevorrichtungen.
- Im Bereich der unteren Haltevorrichtungen waren Mängel an den Schweissnähten vorhanden.

General information on this report

This report contains the Swiss Transportation Safety Investigation Board's (STSB) conclusions on the circumstances and causes of the accident which is the subject of the investigation.

In accordance with Article 3.1 of the 10th edition, applicable from 18 November 2010, of Annex 13 to the Convention on International Civil Aviation of 7 December 1944 and Article 24 of the Federal Air Navigation Act, the sole purpose of the investigation of an aircraft accident or serious incident is to prevent accidents or serious incidents. The legal assessment of accident/incident causes and circumstances is expressly no concern of the investigation. It is therefore not the purpose of this investigation to determine blame or clarify questions of liability.

If this report is used for purposes other than accident/incident prevention, due consideration shall be given to this circumstance.

The definitive version of this report is the original in the German language.

All information, unless otherwise indicated, relates to the time of the accident.

All times in this report, unless otherwise indicated, follow the coordinated universal time (UTC) format. At the time of the accident, Central European Summer Time (CEST) applied as local time (LT) in Switzerland. The relation between LT, CEST and UTC is:
LT = CEST = UTC + 2 hours.

Contents

Final Report

Synopsis

Owner	Goal Verwaltungsgesellschaft mbH & Co., Grünwald, Germany
Operator	Croatia Airlines, Croatian Air Transport Company Ltd., Zagreb, Croatia
Manufacturer	Bombardier Aerospace Inc., Quebec, Canada
Aircraft type	DHC-8-402 (also known as Dash-8 Q400)
Country of registration	Croatia
Registration	9A-CQC
Location	Runway 14 at Zurich Airport, Switzerland
Date and time	27 September 2013, 18:18 UTC

Investigation

The accident occurred on 27 September 2013 at 18:18 UTC and was immediately reported to the former Swiss Accident Investigation Board (SAIB). The investigation was opened on the same day.

The SAIB informed the Canadian and Croatian authorities about the accident. Both authorities appointed an authorised representative and several consultants.

The present final report is published by the Swiss Transportation Safety Investigation Board (STSB).

Summary

On 27 September 2013, a scheduled flight with flight plan call sign CTN 464 from Zagreb (Croatia) to Zurich (Switzerland) was conducted using the Bombardier DHC-8-402 aircraft, registration 9A-CQC. On board were two pilots, two cabin crew members and 60 passengers. After an uneventful flight, the aircraft was established on the localiser and the glide path for an instrument approach on runway 14. The pilots extended the landing gear at a distance of approximately six nautical miles from the runway threshold. Although the main landing gear could be completely extended, it was not possible to extend the nose landing gear.

The flight crew aborted the approach and air traffic control offered the crew entry into a holding pattern to troubleshoot the fault. It was not possible to extend the nose landing gear any further using the non-normal/emergency checklist in the aircraft's quick reference handbook (QRH) or according to the guidelines published in a flight operation service letter from the aircraft manufacturer to the aircraft operator. The flight crew then decided on a landing with the main landing gear extended and the nose landing gear retracted. After the passenger cabin was prepared for an emergency landing and air traffic control had been informed of the situation, a second approach was performed.

The aircraft touched down just before 18:18 UTC on runway 14 at Zurich airport and came to a standstill 540 metres after the nose of the aircraft had made contact with the runway surface. The airport fire brigade was ready to intervene. Fire did not break out. All passengers and crew were able to disembark the aircraft via the front left cabin door.

No passengers or crew members were injured. The aircraft was damaged.

Causes

The accident is attributable to the fact that the flight crew was not successful in extending the nose landing gear and then had to conduct a landing with extended main landing gear and retracted nose landing gear.

The following factor was identified as the direct cause of the accident:

- The WOW cover plate on the nose landing gear was broken on both lower lugs so that it was bent upwards around the upper tab mounts and was trapped in the nose gear mechanism, which prevented the extension.

The crack on the lower WOW cover plate lug is attributed to the following factors:

- The way the WOW cover plate was mounted led to lateral forces on the WOW cover plate and mechanical stress in the area of the upper and lower lugs during operation of the nose landing gear steering.
- There were weld defects in the area of the lower lugs.

Safety recommendations

In the context of the investigation, two safety recommendations were issued.

1 Factual information

1.1 Prehistory and history of the flight

1.1.1 General

For the following description of the prehistory and the history of the flight, the statements of the crew members, the recordings of the cockpit voice recorder (CVR) and digital flight data recorder (DFDR), the entries in the alarm journal of the Zurich Airport Authority and information from the airport fire brigade (Schutz und Rettung Zürich), as well as air traffic control's radar data were used.

During the flight involved in the accident, the 9A-CQC aircraft was operated under instrument flight rules (IFR). The commander was pilot flying (PF) and the co-pilot was pilot not flying (PNF).

1.1.2 Prehistory

The crew of flight CTN 464 began their flight duty on 27 September 2013 at 11:40 UTC. One hour and 15 minutes were scheduled for the flight preparations and briefing. Two flights using the 9A-CQC had already been conducted by the crew before the flight from Zagreb (LDZA) to Zurich (LSZH). The flight crew stated that no technical problems had occurred during these two flights. The aircraft's technical log contained no entries in relation to safety deficits.

The flight from Zagreb to Zurich was conducted by Croatia Airlines under flight plan call sign CTN 464 and radio call sign *„Croatia four six four"*. On board the aircraft were two pilots, two cabin crew members and 60 passengers. Before the flight began, there were approximately 3200 kg of fuel on board. According to the operational flight plan (OFP) this corresponded to a maximum flight time (endurance) of 3:19 hours. A consumption of approximately 1600 kg and a flying time of 1:31 hours were planned for the flight to Zurich. Munich (EDDM) was the planned alternative airport.

1.1.3 History of the flight

On 27 September 2013 at 15:56 UTC the Bombardier DHC-8-402 (also known as Dash-8 Q400) aircraft, registration 9A-CQC, took off from Zagreb Airport. The departure from Zagreb, as well as the climb and cruise were uneventful. During the descent towards Zurich, the automatic terminal information service (ATIS) was obtained and assessed as unproblematic for an approach to Zurich Airport. The pilots then prepared for an instrument approach on runway 14.

With the help of radar vectors, the aircraft was directed around a thunderstorm cell in the area of the AMIKI waypoint, towards the final approach. Approximately 15 nautical miles (NM) north-west of the airport the crew received from air traffic control the last heading instruction to intercept the localiser of the instrument landing system (ILS) for runway 14. Approximately eight nautical miles from the runway threshold, the flight crew established the aircraft on the localiser and the glide path. At 17:26:33 UTC they were instructed by approach control to switch to the Zurich aerodrome control (ADC) radio frequency.

At 17:27:09 UTC, approximately six nautical miles from the runway threshold, the first officer set the gear lever to the DOWN position on the orders of the commander (cf. Annex 1). The flight crew then heard a loud, repetitive noise from the nose landing gear wheelwell, which was later described by the crew as *„like rubber hitting a metal in a repetitive manner"*. The crew had the impression that two components were hitting each other in the nose gear wheelwell. The flight attendant who was directly behind the cockpit also heard *„strange repetitive noises*

coming from the nose gear". The flight crew then checked the landing gear indications on the instrument panel. Both main landing gear indicator lamps were illuminated green, which indicates that the landing gear is extended and locked in position. The indication for the nose landing gear on the other hand was illuminated red, which indicates a discrepancy between the position of the landing gear lever and the position of the nose landing gear.

As a result, the flight crew decided to abort the approach and informed air traffic control at 17:27:42 UTC as follows: *„We have a problem and discontinue the ILS (...)."* The air traffic control officer (ATCO) immediately replied as follows: *„Croatia four six four okay, um then climb straight ahead or are you able to continue visually?"* The crew answered as follows at 17:28:00 UTC: *„Uh we are able to continue visually but not for landing at the moment."* Thereupon the ATCO issued the crew at 17:28:04 UTC the instruction to climb to 4000 ft QNH while maintaining their current heading.

The crew then discussed whether they should retract the landing gear again or not. The commander initially expressed the intention of leaving the landing gear extended, to which the copilot expressed his concern that the continuing noise might mean further damage. Finally the crew decided to retract the landing gear, whereupon the indications for the main landing gear and nose landing gear all indicated retracted gear and the unusual noise stopped.

At 17:28:55 UTC the ATCO asked the crew if they were ready for another approach or if they wanted to enter a holding pattern to troubleshoot the fault. The crew answered as follows at 17:29:02 UTC: *„We need a holding for troubleshooting and we can then report when finished, Croatia four six four."* Then the crew was instructed to change back to the Zurich Arrival air traffic control radio frequency. The commander then requested that the flaps be retracted and told the copilot that they should just fly for the time being and deal with the fault later.

At 17:29:26 UTC the crew reported to the Zurich Arrival ATCO and subsequently received clearance to climb to 6000 ft QNH. After a heading instruction from the ATCO, the commander told the copilot that he now wanted to enter a holding pattern, whereupon the copilot reported to the ATCO as follows at 17:30:51 UTC: *„And Croatia four six four we appreciate uh holding for troubleshooting."* The ATCO immediately replied as follows: *„Croatia four six four, roger, heading zero five zero, vectors towards AMIKI for troubleshooting."* The crew confirmed this instruction. The commander then instructed the copilot to keep the checklists ready and asked him which procedure they were likely to apply. In the ensuing short discussion, the commander stated that they would make another attempt to extend the landing gear in the holding pattern in order to decide which procedure to apply. In his opinion, the nose landing gear had not been extended. The copilot was of the same opinion.

During this discussion, the ATCO issued the crew the instruction to climb to flight level (FL) 70. Shortly thereafter, he gave the crew the instruction to fly directly to the AMIKI holding pattern and climb to FL 90.

At 17:33:19 UTC, the ATCO asked the crew about the nature of the technical problem, to which they replied that they had not been able to extend the nose landing gear and that they would now attempt this again in the holding pattern. Then, while the aircraft was approximately seven nautical miles south-west of AMIKI, climbing above FL 70, the flight crew informed the cabin crew of the problem with the nose landing gear.

At 17:33:54 UTC, the ATCO informed the crew that there was a storm cell eight nautical miles north of the AMIKI waypoint and that they should report back if they were therefore unable to enter the AMIKI holding pattern. The crew con-

firmed the message by pointing out that they could see the storm cell on their weather radar screen.

The flight crew then discussed alternative landing sites, such as Stuttgart. A fuel status of 1650 kg was mentioned and the decision was finally made to land in Zurich after troubleshooting the fault.

At approximately 17:35 UTC the aircraft reached FL 90. The commander then asked for the flaps to be extended to 5°. Following this, the flight crew began to use the alternate landing gear extension checklist, which is described in the aircraft's quick reference handbook (QRH) (cf. Annex 3 and 8).

At 17:36 UTC flight CTN 464 entered the holding pattern. The commander interrupted the copilot while he was reading the introductory checklist note (cf. Annex 3) and asked him to first attempt to extend the landing gear again according to the normal procedure. After the copilot operated the landing gear lever the same unusual noises occurred again; the copilot then set the lever back to the UP (retracted) position upon the command of the commander. The crew then continued to work through the checklist. The sound and voice recordings suggest that during the next three minutes the crew worked through the alternate landing gear extension checklist point by point. However, the flight crew was not successful in extending the nose landing gear even using this alternate procedure.

There was then a brief discussion between the commander and copilot, whereupon the crew consulted a flight operation service letter (FOSL) published by the aircraft manufacturer concerning landing gear problems (cf. chapter 1.17.2 and Annex 6). This FOSL contains information on how the landing gear mechanism can be reset for another attempt to extend using the normal procedure, as well as the points to be taken into account in a landing with the nose landing gear retracted. The commander selected the following option: *„Opting to cycle the landing gear in an effort to extend the nose gear from this abnormal situation would require a reset of Alternate Extension procedure. (…).”* After the crew reset the system in accordance with this FOSL there followed another unsuccessful attempt to extend the landing gear using the normal procedure. The cockpit crew then took the decision to land at Zurich Airport with the nose landing gear that from their perspective was probably retracted.

At 17:48 UTC, the flight crew informed the cabin crew of the impending landing with the nose landing gear retracted and gave instructions to relocate passengers according to the FOSL (cf. Annex 6 and chapter 1.17.1.2.4). The copilot objected to this procedure on the basis of exceeding the weight and balance limits, so the crew decided to relocate passengers from maximum two or three rows of seats from the front to the rear of the aircraft. The commander then informed the passengers in Croatian and English of an impending landing with the nose landing gear retracted and of the fact that the cabin crew would then instruct them on how to behave during an emergency landing. He also stated that they would again attempt to extend the nose landing gear, but that he could not promise success.

While the commander spoke with the passengers, the ATCO informed the copilot at 17:49:35 UTC that the previously observed storm cloud was now moving south and that the crew at any time could move their holding pattern south if they want. He also stated that the air traffic control officers in the tower had observed on the first approach that the nose landing gear did not appear to be extended. The copilot answered as follows at 17:50:00 UTC: *„Uh that's the case uh our nose gear also our indication is that the nose gear didn't go down. We tried to cycle but no effect, we'll try one more, then we'll call you to see further, but we won't be staying in holding anyhow much longer.”*

The crew then again attempted to extend the landing gear using the normal and the alternate procedures.

During this time the cabin crew prepared the cabin and galley for the planned emergency landing. As discussed with the cockpit crew, the passengers seating in the first three rows of seats were assigned to other seats in the rear of the aircraft. Able-bodied passengers were also selected and assigned suitable seating positions to help in the event of an evacuation. The passengers were informed about evacuation procedures and opening the aircraft doors.

After the flight crew was again not successful in extending the nose landing gear using both the normal and alternate procedures, the commander instructed the copilot to declare an emergency. At 17:55:51 UTC the copilot reported to the ATCO as follows: *„Uh Croatia four six four we have to declare Mayday Mayday Mayday, we are now holding at AMIKI, flight level niner zero, still one thousand three hundred kilos of fuel, I have sixty passengers and we are unable to uh release the nose gear down."*

At approximately 17:57 UTC, the aircraft left the AMIKI holding pattern (cf. Annex 2). The crew then agreed with air traffic control an approach on runway 14 of at least 60 nautical miles. At 17:58:13 UTC, air traffic control informed the fire brigade of the imminent landing of 9A-CQC with retracted nose landing gear. At 17:58:22 UTC, the crew informed the ATCO that they would probably be unable to leave the runway after landing and asked if they would therefore be better advised to land on runway 16 instead of runway 14. The ATCO stated that runway 14 was planned for the landing. Then the crew requested the provision of the fire brigade. At 17:58:42 UTC the ATCO informed the crew that the fire brigade had already been alerted.

The flight crew then conducted a briefing regarding the imminent landing and the subsequent measures. In particular, these involved performing an emergency evacuation of the cabin in the event of fire and initiating a controlled disembarkation if fire did not break out.

In the meantime, the cabin crew explained to the passengers the seat position to take for the imminent landing (brace for impact, cf. chapter 1.17.1.2.4).

Meanwhile, air traffic control had referred all other aircraft on the Zurich Arrival frequency to a different frequency and at 18:01:47 UTC gave the crew the following information: *„Croatian four six four you are now the only one on my frequency, go ahead."* The crew thanked air traffic control and informed the ATCO that the passengers would probably disembark the aircraft on the runway after landing and that appropriate preparations should be made.

At 18:02 UTC, the crew received clearance to initiate a descent. Shortly thereafter the cabin crew reported to the flight crew that all preparations had been completed and that it would take only two minutes for them to be able to give the final OK for landing. The commander informed the cabin crew that the engines would be shut down during the landing roll after touchdown and that a controlled disembarkation would be very likely. The copilot pointed out to the cabin crew that after landing the attitude of the aircraft would be different to that after a normal landing. Both cabin crew members also heard this information on the interphone.

At 18:04:49 UTC, the crew reported to the ATCO that they would be ready for the final approach in two minutes. Air traffic control then instructed the crew to fly on a westerly heading and descend to 4000 ft QNH. The commander then asked the copilot whether preparations for landing were complete. The copilot then began to read out again from the FOSL the points to be considered when landing with retracted nose landing gear (cf. Annex 6). While the copilot was reading out

these points, the commander interrupted and mentioned that they still had to work through the emergency landing checklist and asked the copilot to request air traffic control for an extension of the approach by five minutes, which the copilot did at 18:06:14 UTC. Air traffic control then requested the crew to turn right onto a northwesterly heading onto the downwind leg of the approach and to stop their descent at 5000 ft QNH.

Over the next approximately four minutes, from approximately 18:07 until approximately 18:11 UTC, the crew worked through the emergency landing checklist in the QRH (cf. Annex 7). For a long time they were involved with the search for the ground proximity warning system (GPWS) electrical circuit breaker (CB). In the checklist position A1 is specified for this on the avionics CB panel. Unlike the checklist and aeroplane operating manual (AOM), there is no designation of the CB panels in the cockpit of the aircraft. While searching for the CB panel the crew found a circuit breaker in the A1 position with the designation *„pass brief sys[1]"*. Finally, the commander found a circuit breaker with the designation EGPWS in the A1 position on another CB panel. The copilot suggested pulling that CB and this was performed. The commander also gave orders not to dump the cabin pressure and not to switch on the emergency locator transmitter (ELT).

In this phase, air traffic control asked whether the crew was ready for the base leg of the approach within the next minute, to which they answered in the affirmative. At approximately 18:08 UTC, the cabin crew informed the commander that the cabin was ready for landing. At 18:08:18 UTC, as the aircraft was approximately two nautical miles from the northern boundary of the terminal control area (TMA), the ATCO instructed the crew to turn left onto a southwesterly heading. He also offered the crew the option of crossing the localiser if they required more time. The copilot replied that they would accept this offer. At 18:09:58 UTC, the ATCO instructed the crew to turn left onto a southerly heading due to the airspace structure.

At 18:10:51 UTC, the crew reported that they were ready for the approach. Air traffic control then issued the crew the heading to intercept the localiser and clearance to 4000 ft QNH. At 18:11:13 UTC, the ATCO gave the crew the following information: *„And Croatian four six four, you will intercept at niner miles touch down."*

At 18:12:06 UTC, the crew extended the flaps to 10°. As the nose landing gear was not extended a continuous warning tone sounded; this continued until the power supply was switched off after landing. After the accident the crew stated that this continuous warning tone had been a distraction. A little later, the crew extended the flaps to 15°.

While turning onto the localiser the flight crew again worked through the points to be performed in the event of an evacuation. Shortly before 18:14 UTC, the aircraft was established on localiser and glide path of the runway 14 ILS. At 18:13:42 UTC, the copilot reported as follows to the ATCO: *„Croatia four six four, established."* Ten seconds later the copilot gave the cabin crew the following information via the public address (PA) system: *„Cabin crew, prepare for landing."*

In the meantime, preparations had been made on the ground for the planned emergency landing.

At 18:14:02 UTC, the crew was requested to change to the aerodrome control frequency, which they did immediately. At 18:14:19 UTC, the ADC controller cleared the crew to land on runway 14.

[1] *„pass brief sys"* means passenger briefing system

At 18:15:33 UTC the landing configuration was prepared; this included a flap setting of 35°. The commander requested the landing checklist, which the copilot executed immediately. Subsequently the commander briefly mentioned again some important points like pitch and speed regarding the imminent landing.

Shortly before 18:18 UTC, the aircraft touched down on runway 14 on its main landing gear, approximately 450 m after the runway threshold. While touching down and during the subsequent landing roll on the main landing gear, the copilot reported the pitch and, upon request, the speed, to the commander. In this phase the pitch was less than 4° attitude nose up. The commander described this phase as follows:

„(…) we were able to keep the nose up until about 60 kt. When passing 80 kt there were some difficulties to keep the lateral direction and to maintain the aircraft on the runway. With the help of the rudder I was able to regain control. At 60 kt I gently lowered the nose to the ground (…).”

Approximately 1000 m after touchdown the nose of the aircraft made contact with the runway surface. After another 540 m, the aircraft came to a standstill approximately on the centerline of the runway (see Figure 1 and 5). The commander stated that he braked slightly and used no reverse thrust during the landing. Shortly after the aircraft came to a standstill the parking brake was set and both engines shut off. The commander commented that they had been ready to pull the fire handles. He stated that they had refrained from doing so because no fire warning was displayed and the fire brigade, which was at the aircraft's location only a few seconds after it came to a standstill, notified them via aerodrome control that no fire had broken out.

Figure 1: The aircraft immediately after coming to a standstill, photographed from the leading fire brigade engine. The propellers are still turning.

The commander promptly instructed the cabin crew to initiate a controlled disembarkation and informed them that the passengers should leave their hand luggage on board. He then ordered the copilot to work through the parking checklist.

The cabin crew followed the instructions of the commander and immediately initiated a controlled disembarkation via the front left cabin door. The passengers kept on their shoes but left the hand luggage back. At 18:22 UTC the copilot reported to air traffic control that the disembarkation was complete.

No passengers or crew members were injured. The aircraft was damaged.

1.1.4 Location and time of the accident

Accident location	Runway 14 at Zurich Airport, Switzerland
Date and time	27 September 2013, 18:18 UTC
Lighting conditions	Night
Coordinates	47° 28' 11" N 8° 33' 11" E (WGS 84)
Elevation	420 m above mean sea level (AMSL), 1378 ft AMSL
Map of Switzerland	Sheet no. 1071, Bülach, scale 1:25,000

1.2 Injuries to persons

Injuries	Crew	Passengers	Total number of occupants	Others
Fatal	0	0	0	0
Serious	0	0	0	0
Minor	0	0	0	0
None	4	60	64	Not applicable
Total	4	60	64	0

1.3 Damage to aircraft

The aircraft was damaged (cf. chapter 1.12).

1.4 Other damage

There was no other damage. The runway was swept after the accident.

1.5 Personnel information

1.5.1 Flight crew

1.5.1.1 Commander

1.5.1.1.1 General

Person	Croatian citizen, born 1973
Licence	Airline transport pilot licence aeroplane (ATPL(A)) according to European Aviation Safety Agency (EASA)

All available evidence suggests that the commander started duty well rested and in good health. There are no indications that fatigue played a role.

1.5.1.1.2 Flying experience

Total	7716 hours
of which as commander	3229 hours
of which on the type involved in the accident	3114 hours
during the last 90 days	188 hours
of which on the type involved in the accident	188 hours

1.5.1.2 Copilot

1.5.1.2.1 General

Person	Croatian citizen, born 1978
Licence	ATPL(A) according to Joint Aviation Requirements (JAR)

All available evidence suggests that the copilot started duty well rested and in good health. There are no indications that fatigue played a role.

1.5.1.2.2 Flying experience

Total	4191 hours
of which on the type involved in the accident	2520 hours
during the last 90 days	175 hours
of which on the type involved in the accident	175 hours

1.6 Aircraft information

1.6.1 General information

Registration	9A-CQC
Aircraft type	DHC-8-402 (also known as Dash-8 Q400)
Characteristics	Twin engine regional aircraft with turboprop propulsion and 76 seats, constructed as a cantilever high-wing monoplane in all-metal construction with retractable undercarriage in nose landing gear configuration.
Manufacturer	Bombardier Aerospace Inc., Quebec, Canada
Owner	Goal Verwaltungsgesellschaft mbH & Co, Grünwald, Germany
Operator	Croatia Airlines, Croatian Air Transport Company Ltd., Zagreb, Croatia
Mass and centre of gravity	The mass of the aircraft at the time of departure was approx. 27 400 kg. The mass of the aircraft at the time of the accident was approx. 25 400 kg. Both the mass and centre of gravity were within the permitted limits according to the aircraft flight manual (AFM) during the entire flight.

1.6.2 Landing gear

1.6.2.1 General

The landing gear of the DHC-8-402 is of a tricycle configuration. The nose landing gear (NLG) is located in and under the lower fuselage forward of the cockpit and retracts forward into the nose landing gear bay of the fuselage. The two main landing gears (MLG) are located in and under the left and right engine nacelles, respectively. The MLG retract rearward into the main landing gear bays of the engine nacelles.

Since the main landing gear in the present case functioned faultless during the accident flight only the nose landing gear will be part in the following description.

1.6.2.2 Design

The nose landing gear is designed according to the levered suspension principle that was already patented in 1943. This kind of design is based on the fact that telescope compression legs, directly connected with the wheel axle, revealed certain deficiencies which are inherent in the system. In particular, it is impossible so to position the leg that all combinations of vertical load and side loads induced by drift landings, and drag loads due to braking, shall give resultant loading which is truly axial in the shock absorber. Consequently the telescoping strut is subjected to bending. The arrangement in the levered suspension type consists essentially of pin-jointing the working parts of the undercarriage so that the shock absorber is pin-jointed to a beam or lever which also carries the wheel (see Figure 2).

In the case of telescopic compression leg, the shock absorber has nominally the same linear travel as the wheel. With levered suspension this movement of the piston is reduced by an amount corresponding to the leverage ratio, and this results in a smaller and more compact shock absorber. This also means that less space is used which plays a role regarding retractable landing gears.

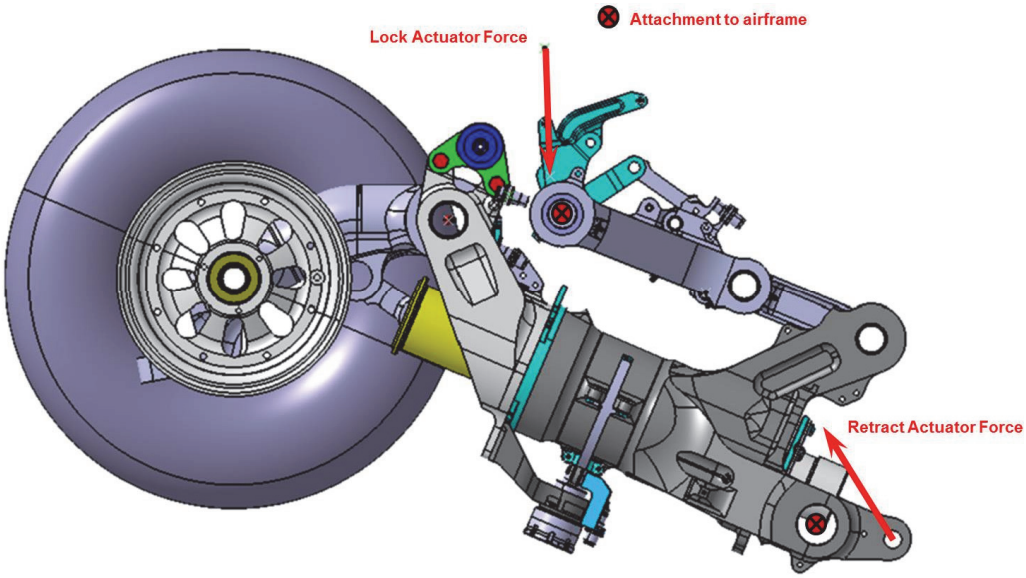


Figure 2: Nose landing gear in retracted position (image from the gear manufacturer, adapted by the STSB). Taxi light and WOW cover plate not shown (cf. chapter 1.16).

Hydraulic retraction and extension is done by the retract actuator whose action line is pictured schematically in Figure 2. A second and smaller lock actuator is used to unlock the gear if retracted. It's action line is also pictured schematically in Figure 2. Alternatively, it is possible to unlock the gear by hand (cf. chapter 1.6.2.5).

The nose landing gear has four doors. The two forward doors are hydraulically operated and the two aft doors are mechanically operated. If the gear is retracted all four doors are closed.

1.6.2.3 Unlock mechanism

In order to extend the nose gear it must first be unlocked. The respective mechanism is independent of whether the gear has been extended normally (cf. chapter

1.6.2.4) or by the alternate procedure (cf. chapter 1.6.2.5). The only difference is that the required force is either brought up hydraulically via the lock actuator or by hand via cables and rolls.

The unlock mechanism is schematically pictured in Figure 2. The drag brace (the upper and lower drag strut) is initially biased slightly under center and the lock mechanism (the upper and under lock link) slightly over center when the NLG is up and locked. Applying a force onto the pivot tube assembly, either by hydraulic pressure via the lock actuator or mechanically via cables and rolls, breaks the over center of the lock mechanism and the gear gets unlocked.

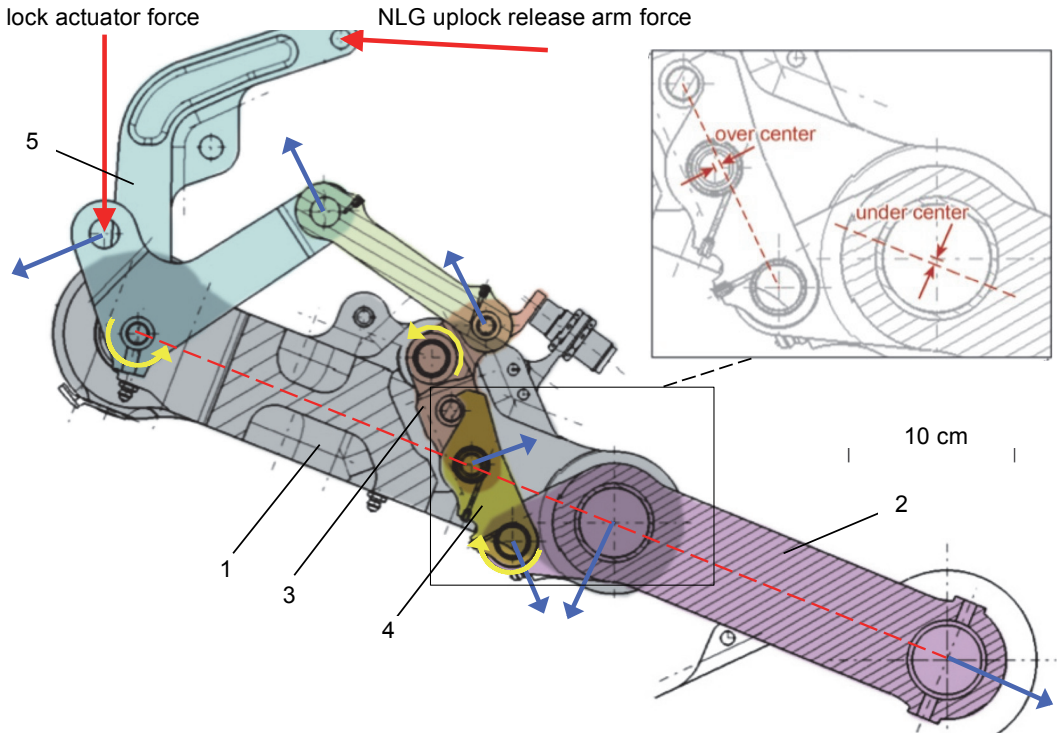


Figure 3: Unlock mechanism, drawn by the manufacturer and adapted by the SUST. The respective parts are color dyed for better recognisability. The movement and the rotation direction of the respective parts, as a result of the external forces (red arrows) are schematically pictured by blue/yellow arrows.
1: upper drag strut
2: lower drag strut
3: upper lock link
4: lower lock link
5: pitot tube assembly

In the course of the dead center overcome of the lock mechanism, the connection bearing between upper and lower drag strut will move 0.4 millimeter diagonally downwards. This means that the under center position of the two drag struts will initially be slightly reduced.

1.6.2.4 Normal landing gear extension

While extending the nose landing gear, the following steps will take place:

1. Landing gear selector lever is moved to the down (DN) position. The selector valve then routes hydraulic system pressure to the extend side of the landing gear hydraulic system (MLG and NLG).
2. The solenoid sequence valve then directs the pressure first to the forward wheel bay door actuator, causing the forward wheel bay doors to start opening.

3. At approx. 92% travel of the forward doors, the mechanical sequence valve that is driven by the forward door linkage is opened, which then simultaneously routes hydraulic pressure to extend the lock actuator (to unlock the drag brace mechanism) and retract the retraction actuator (to extend the gear).
4. The force from the retract actuator initially forces the drag brace further away from being in-line. However, the lock actuator is designed to overcome the initial opposing force from the retract actuator. Overall, in the course of the dead center overcome of the lock mechanism the under center position of the two drag struts will initially be slightly reduced before the gear can be extended by the effect of the retract actuator.
5. If the NLG is down and locked, the solenoid sequence valve gives pressure again free to the actuator of the two forward gear doors so that they can close.

The hydraulic pressure is supplied by the No. 2 hydraulic system at a nominal pressure of 3000 psi; however, recordings of the flight involved in the accident showed usual pressures of around 3030 psi and peaks of up to 3100 psi.

From Q400 iron bird test data, the lock actuator requires an approximate bore pressure of 1500 psi to unlock the mechanism during normal extension of the NLG in the hangar (i.e. without a jam and without air loads).

1.6.2.5 Alternate extension procedure

The NLG alternate extension is conducted via a cable and pulley-cam system that is manually actuated from the cockpit. The following steps will take place:

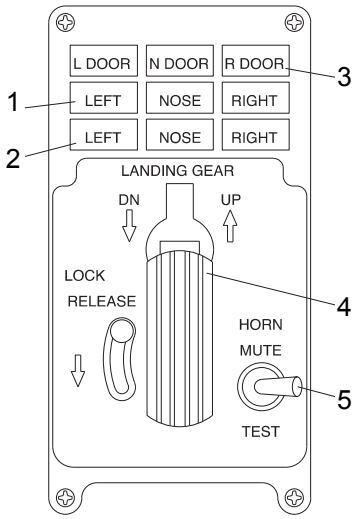
1. The landing gear inhibit switch, located in the ceiling overhead the right pilot seat, has to be set to the INHIBIT position. Then the landing gear alternate release door, located next to the inhibit switch in the ceiling of the cockpit, has to be opened. This has amongst others the effect that the landing gear's hydraulic system will be emptied and isolated from hydraulic system No. 2.
2. Now the landing gear alternate extension door, located between the two pilot seats in the cockpit floor, has to be opened in order to give access to the alternate release handle (cf. Annex 8 and Figure 3).
3. Pulling the alternate release handle initially unlocks the forward gear doors. Tension springs in the NLG doors mechanism then pull the doors open. Then the lock mechanism will be released and the NLG free-falls to the fully extended position, with help of the airflow over the fuselage.

The pulley cam mechanism lets the full force of the pull be concentrated first on the release of the NLG forward doors and only then on the NLG uplock release arm (cf. Annex 8 and Figure 3).

The whole system is designed to be actuated by a handle pull force not exceeding 90 lb (equal to 41 kg or approximately 400 N).

1.6.2.6 Indications and warnings

The status of the landing gear, two main landing gears and one nose landing gear, will be shown to the pilots in the cockpit with lamps as follows:



Legend:

1: Illuminates green if the respective gear is down and locked.

2: Illuminates red if the respective gear status does not correspond with the gear lever (4) position, i.e. either not retracted and locked (UP) or not extended and locked (DN).

3: Illuminates amber if the respective gear door is open.

4: Gear lever.
Illuminates amber if the gear is in transit or if one of the gear status lights is illuminated red (2).

5: Warning horn mute/test switch.

Figure 4: Landing gear control panel in the cockpit

In addition a LDG GEAR INOP (landing gear inoperative) caution light illuminates in the caution and warning panel in the cockpit if any anomaly is sensed in the gear function. This light also illuminates if the landing gear inhibit switch is set to INHIBIT.

1.7 Meteorological information

1.7.1 General meteorological situation

A flat area of high pressure extended from Scandinavia through Central Europe to the Black Sea. There was a nearly stationary air mass boundary over southern Germany. In the humid tropical air an isolated but intense thunderstorm cell was developing in the Lake Constance area, approximately 50 km north-east of Zurich Airport. The storm was active before and during the landing of flight CTN 464 in Zurich. Sheet lightning was observed at Zurich Airport, but no thunder was audible.

1.7.2 Weather at the time and location of the accident

There was no precipitation at Zurich Airport. A light wind was blowing from various directions at one knot. The visibility was 14 kilometres. No clouds were observed below 8000 feet above ground. Neither cumulonimbus nor towering cumulus clouds were observed in the vicinity of Zurich airport.

1.7.3 Astronomical information

Position of the sun	Azimuth: 280°	Elevation: -12°
Lighting conditions	Night	

1.7.4 Aerodrome meteorological reports

At the time of the accident, the following meteorological aerodrome report (METAR) applied:

METAR LSZH 271820Z VRB01KT CAVOK 18/16 Q1014 NOSIG=

This means: On 27 September 2013, shortly before the 18:20 UTC issue time of the aerodrome meteorological report, the following weather conditions were observed at Zurich Airport:

Wind	Direction variable at 1 kt

CAVOK	The term CAVOK (ceiling and visibility OK) is used for visibility, weather and cloud if the following conditions are met (at the time of observation): – Meteorological visibility 10 km or more. – No cloud below 5000 ft above aerodrome level (AAL) or below the highest minimum sector altitude (MSA) if this is greater than 5000 ft AAL. – No cumulonimbus (CB) or towering cumulus (TC) at any altitude. – No significant weather phenomena.
Temperature	18 °C
Dewpoint	16 °C
Atmospheric pressure	1014 hPa, pressure reduced to sea level, calculated using the values of the ICAO standard atmosphere.
Landing weather forecast	No significant changes expected in the two hours following the weather observation.

1.8 Aids to navigation

All navigation aids were in normal operation at the time of the accident and were available without restriction.

1.9 Communications

Radio communication between the crew and air traffic control took place in English without any technical difficulties. Communications between the crew members took place in English and Croatian.

1.10 Aerodrome information

1.10.1 General

Zurich Airport is in north-east Switzerland. In 2012, the passenger volume was 24.8 million with some 270 000 movements.

The reference elevation of the airport is 1416 ft above mean sea level (AMSL) and the reference temperature is 24.0 °C.

1.10.2 Runway equipment

Zurich Airport is characterized by a system of three runways. Runways 16 and 14 are equipped with a Category III instrument landing system (ILS) and runway 34 is equipped with a Category I ILS. Runway 28 is equipped with an uncategorised ILS, which has increased weather minimums in comparison to Category I. The runways are therefore suitable for precision approaches.

The Zurich Airport runways have the following dimensions:

Runway	Dimensions	Elevation of runway thresholds
16/34	3700 x 60 m	1390/1388 ft AMSL
14/32	3300 x 60 m	1402/1402 ft AMSL
10/28	2500 x 60 m	1391/1416 ft AMSL

At the time of the accident the entire runway lengths of all three runways were available for landings.

1.10.3 Rescue and fire-fighting services

Zurich Airport is equipped with Category 10 fire-fighting resources. The airport's professional fire brigade is on permanent standby duty during flight operations.

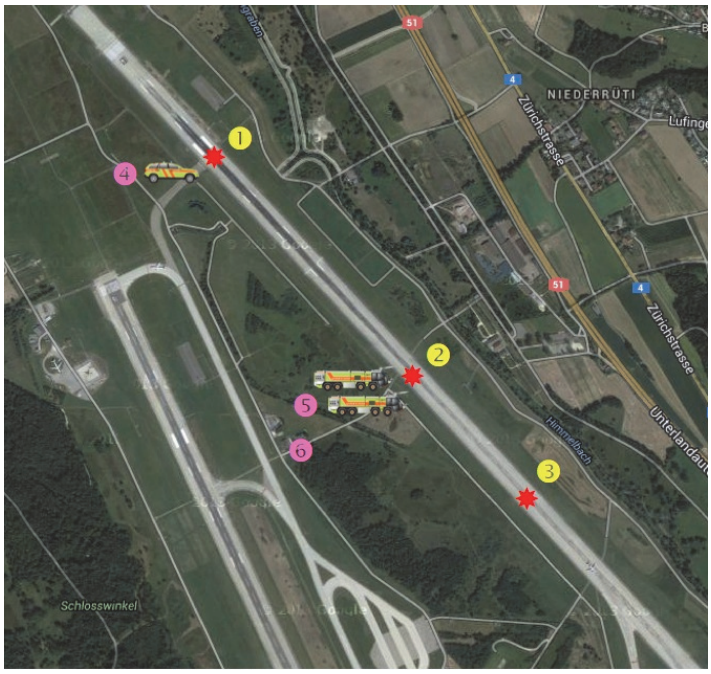
At 17:58 UTC, air traffic control triggered Alarm 21[2]. At the same time it reported that a Dash-8 with a landing gear problem would land on runway 14 in ten minutes. This landing gear problem was later more precisely defined as defective nose landing gear.

The leading fire engine with radio call sign „Florian 1" moved into position at the level of taxiway G, in the touchdown zone of runway 14, in order to observe the landing. On the satellite road, 900 metres further along runway 14, two heavy airfield fire engines were held at the ready (see Figure 5). A third airport fire engine and a universal fire engine were ready for deployment at the southern end of runway 14. At 18:02 UTC, the fire brigade reported to the ATCO that they were ready for deployment.

During the aircraft's landing, the driver of the „Florian 1" vehicle reported that the nose landing gear was not extended. After consultation with air traffic control, he followed the aircraft on runway 14. When the aircraft passed the satellite road, the two fire engines also immediately followed the aircraft onto the runway after consultation with air traffic control. They were with the aircraft and ready for deployment just seconds after the aircraft came to a standstill, and even before the engines had been shut down (see Figure 1). The fire brigade had radio contact with aerodrome control and informed them that fire had not broken out. Aerodrome control immediately forwarded this message to the crew at 18:18:39 UTC (cf. chapter 1.1.3, History of the flight). The fie brigade found some heating using a heat image camera. Since they recognized some smoky taste at the same time they cooled the badly accessible front area of the aircraft using a CO_2 extinguisher.

The fire brigade remained on standby until the passengers had disembarked the aircraft and then coordinated the recovery work.

[2] Alarm 21 means that the landing will take place within the next 15 minutes. The fire brigade team must take their seats in the respective fire engines and drive to the respective operational locations.



❶ Main landing gear touches down
❷ Nose makes contact with the runway surface
❸ Aircraft comes to a standstill
❹ „Florian 1" vehicle
❺ Airport fire engines
❻ Satellite road

Figure 5: Part of the fire brigade's deployed fleet according to the information by Schutz und Rettung Zürich.

1.11 Flight recorders

1.11.1 Flight data recorder

Type	SSFDR P/N 980-4700-027
Manufacturer	Honeywell International Inc., Phoenix, Arizona, USA
Number of parameters	304
Recording medium	Solid state memory
Duration of recording	approx. 100 hours

It was possible to evaluate the digital flight data recorder (DFDR) and all available data was available to the investigation.

1.11.2 Cockpit voice recorder

Type	SSCVR P/N 980-6022-011
Manufacturer	Honeywell International Inc., Phoenix, Arizona, USA
Number of parameters	4 channels
Recording medium	Solid state memory
Duration of recording	2 hours

It was possible to evaluate all four channels of the cockpit voice recorder (CVR) and these were available to the investigation.

1.12 Wreckage and impact information

The aircraft touched down on runway 14 with its main landing gear, at approximately the level of taxiway G and approximately 450 m after the runway threshold. After approximately another 1000 m, the nose of the aircraft made contact with the runway. The two forward nose landing gear doors were torn off. After the accident, evidence of contact with a landing gear door was detected on at least one propeller blade. Both landing gear doors indicated abrasion on the inner sur-

faces and edges. These point down when the landing gear doors are open and close against each other when closed.

The aircraft then skidded in a forward direction on its nose along the runway, drifting slightly to the right, for a distance of 540 m. In the process, sparks could be observed. Various smaller parts around the nose landing gear, the nose landing gear wheelwell and the forward underside of the fuselage were torn off. The aircraft finally came to a standstill slightly to the right of the centerline of runway 14 (see Figure 1 and 5).

The runway was not damaged. The torn off parts were collected and the runway was then swept using a machine.

Recovery of the aircraft took place by lifting the nose with the aid of a mobile crane. It was then that the first pictures of the nose landing gear and the nose landing gear wheelwell were taken (see Figure 7). The aircraft nose was then lowered and attached to a flat trailer. This made it possible to transport the aircraft and locate it in a hangar ready for further investigation (cf. chapter 1.16). Throughout the entire recovery, no modifications were made to the nose landing gear and no attempts were made to extend it.

1.13 Medical and pathological information

After the accident, the flight crew was subjected to a test for alcohol and the presence of other exogenous substances. All such analyses yielded negative results for both pilots.

1.14 Fire

Fire did not break out. Sparks were observed as the nose of the aircraft slid over the runway surface. The underside of the forward fuselage section was then cooled by the airport fire brigade.

1.15 Survival aspects

There was no immediate danger to either the crew or the passengers because the airframe remained intact, no fire broke out, the aircraft did not leave the runway and a rescue team was at the ready.

1.16 Tests and research

1.16.1 Tests in relation to the landing gear extension mechanism

After the damaged aircraft was towed from the runway, the aircraft nose was raised and jacked. An attempt was then made to extend the nose landing gear from the cockpit using the alternate release handle. The force exerted on the alternate release handle was successively increased and measured with a Newton meter. When a force of 543 Newton, corresponding to 55 kg (122 lb), was reached on the alternate release handle the nose landing gear finally extended.

It was found that the cover plate which protects the two weight on wheels (WOW) sensors was broken on the lower left and right lugs. This weight on wheels proximity switch cover plate [hereinafter referred to as the WOW cover plate] was discovered bent upwards around the upper tab mounts (see Figure 6). Photographs taken at the site of the accident also revealed that the WOW cover plate was jammed in the nose landing gear mechanism (see Figure 7 and 8). It can be seen that it became trapped between the drag brace, the taxi light, the supporting lubs and possibly the respective bracket.

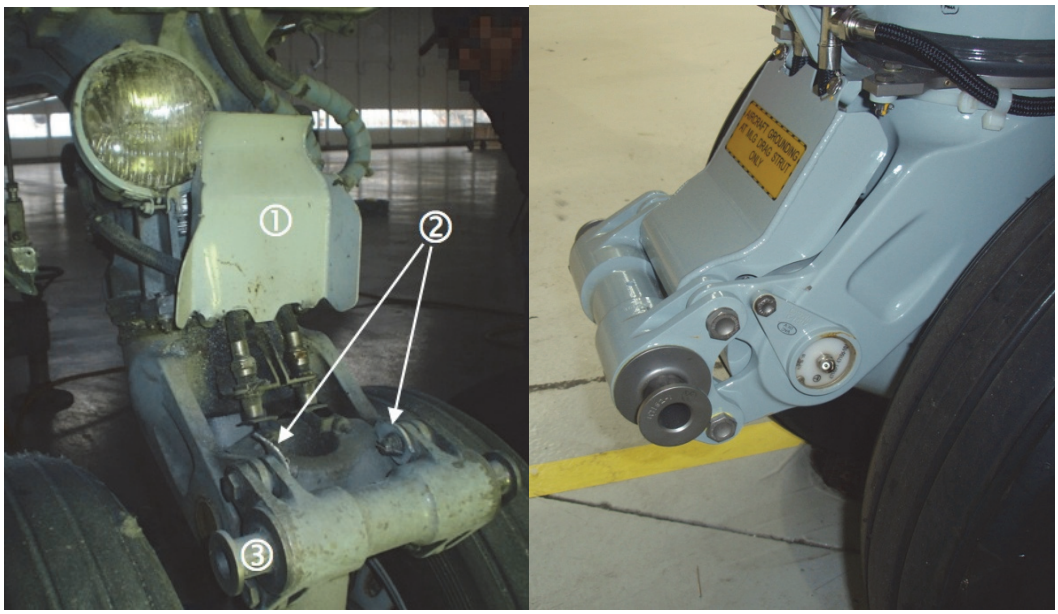


Figure 6: Left: WOW cover plate as it was discovered after the nose landing gear was extended
Right: WOW cover plate in its normal state.
1: WOW cover plate
2: lower lugs (broken)
3: tow fitting assembly

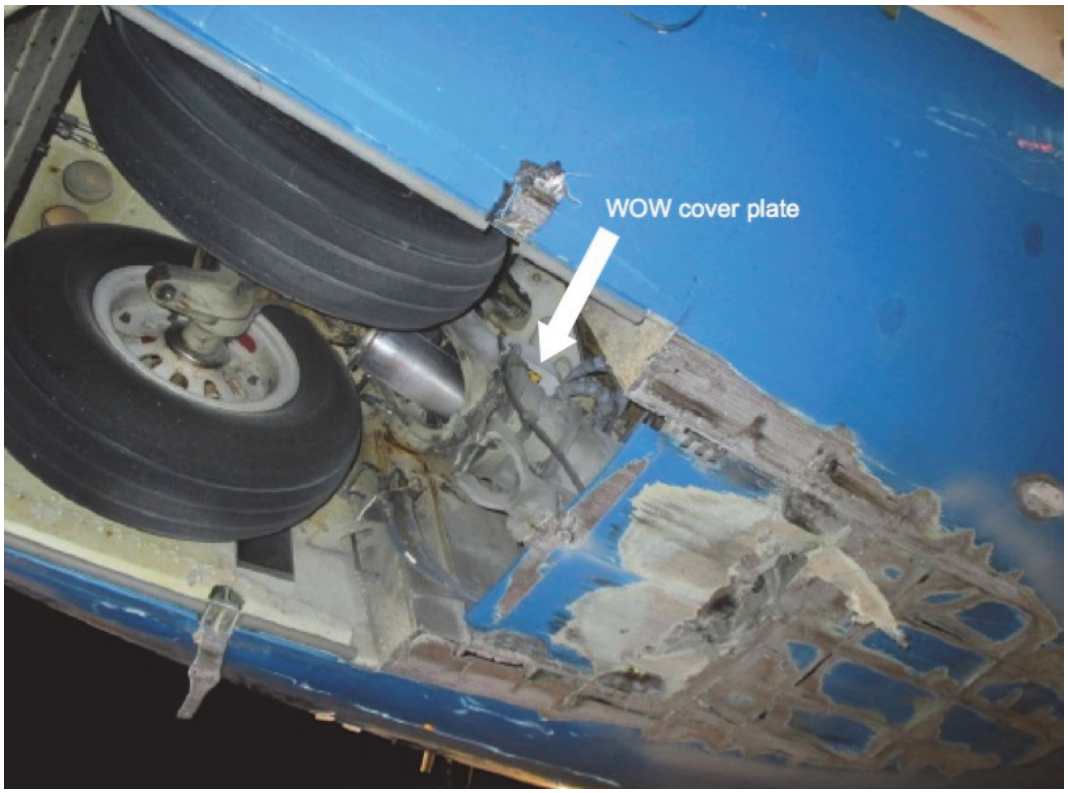


Figure 7: The nose landing gear WOW cover plate trapped between the upper and lower drag struts of the nose landing gear. This photo was taken at the scene of the accident.

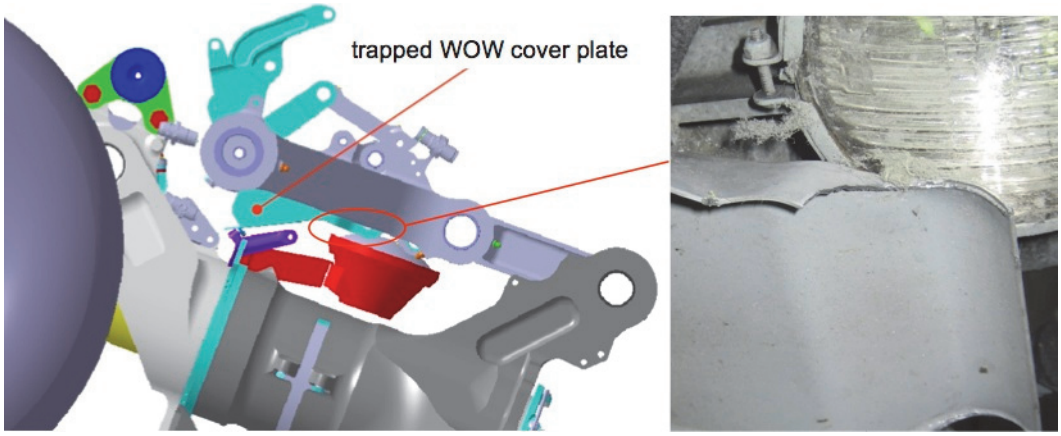


Figure 8: Left: The trapped nose landing gear WOW cover plate. Simulation picture created by the gear manufacturer.
Right: view from above, upwards bent WOW cover plate and taxi light.

After the damaged WOW cover plate was removed, it was possible to easily and repeatedly extend and retract the nose landing gear using the normal and the alternate extension procedure. The tensile force required to extend the landing gear using the alternate release handle with the damaged WOW cover plate removed was 334 Newton, corresponding to 34 kg (75 lb).

1.16.2 Investigation of the nose landing gear WOW cover plate

The WOW cover plate is available as a so-called PMA[3] or OEM[4] part. The WOW cover plate in the accident under investigation was a PMA part.

A detailed metallurgical analysis of the fractured surfaces of the two broken lower lugs was performed by the Swiss Federal Laboratories for Materials Science and Technologies (EMPA). The following results were found:

- *„Most of the fractured surfaces were destroyed by secondary mechanical effect. There are no longer any fracture characteristics to identify in the destroyed areas. A reliable description of the fractured surface is therefore no longer possible.*
- *Small, undamaged areas of the fractured surfaces on both lugs revealed a freely solidified set surface (characteristic surface structure formed when liquid metal solidifies).*
- *A small area of shear lines was discovered on the right lug. Shear lines are characteristic of a ductile forced fracture under shear stress.*
- *Freely solidified surfaces in the fractured surface through the weld material are a clear indication of welding defects such as porosity and/or hot cracking.*
- *A fine, second (minor) crack was observed below the fractured surface of the left lug.*
- *This minor crack was mechanically opened, investigated and compared with the main crack. The exposed fractured surface revealed a mixture of freely solidified surfaces and fatigue cracks and a forced fracture (the latter took place under laboratory conditions)"*

[3] PMA: parts manufacturer approval. This means a part that is neither produced by the manufacturer nor by any of his subcontractors but is produced by a certified third party.

[4] OEM: original equipment manufacturer. This means an original part that is either built by the manufacturer or by any of his subcontractors.

1.16.3 Investigation of other WOW cover plates

For comparative purposes, the EMPA was provided with five other WOW cover plates. The WOW cover plates were from Croatia Airlines DHC-8-402 aircraft and were all taken out of service due to broken upper lugs. The lower lugs were intact.

An X-ray analysis of the two lower WOW cover plate lugs yielded the following results:

- *„All five investigated cover plates show a certain amount of detectable welding defects.*
- *Most significant are the defects in the cover plate removed from A/C 9A-CQE."*

The WOW cover plate on the 9A-CQE aircraft was the only one of the five WOW cover plates to be a PMA component, like the WOW cover plate on the 9A-CQC aircraft that was involved in the accident. This WOW cover plate therefore underwent an in-depth investigation involving destructive testing of the weld between the two lower lugs. The following conclusions were made:

- *„A major part of the opened weld revealed freely solidified surface similar as it has been observed on the accident part 9A-CQC. This also corresponds with the findings of the radiographic investigation.*
- *Almost the entire remaining area shows multiple fatigue crack origins, starting along the welding defect(s) as well as at the ID surface. These cracks later interconnected into two main fatigue cracks running towards each other (reversed bending).*
- *The smallest area resembles the dimple fracture created in the lab to open the segment.*
- *The indications from the radiographic investigations could be confirmed as welding cavities (…).*
- *The extension of the fatigue cracks (…) deflected from the weld into the HAZ (heat affected zone) / Substrate at the location of the section."*

EMPA drew the following conclusions from the investigation of the WOW cover plates of the aircraft involved in the accident and the five identical WOW cover plates:

- *„While the primary fracture surfaces of the accident part are severely damaged, the opened secondary crack clearly shows that fatigue cracking, starting at welding defects, is occurring.*
- *Compared with the findings on the cover plate removed from 9A-CQE, showing an almost identical image in an earlier state, it is safe to assume that the failure of the accident part has been initiated by the presence of pronounced welding defects.*
- *The radiographic investigation of the reference parts shows a tendency that the PMA parts contain more severe defects than the OEM-parts, but this observation is statistically not relevant (one PMA-part compared with 4 OEM-parts (…).*
- *Since a certain amount of defects can be found on all parts, the question regarding inspection and acceptance criteria arises.*
- *Since most of the defects are internal, an x-ray inspection would be required to detect them after welding."*

Finally, the EMPA investigation report states the following:

- *„The root cause of the NLG cover plate failure has been initiated during the manufacturing (welding). The mounting location of the cover plate leads to a cyclic loading caused by the airflow. Therefore a certain (welding) quality is required to avoid such fatigue failures.*
- *We therefore strongly recommend reviewing not only the manufacturing and inspection processes but also the parts out in the field.*
- *The „reference" plate removed from 9A-CQE also shows stable (fatigue) crack growth to a certain extent.*
- *It is likely that more plates will fail if no corrective measures are or have been taken."*

Due to the great number of broken WOW cover plates on the operator's Q-400 fleet, it seemed to be adequate to have a closer look at how frequently the WOW cover plates had to be replaced.

1.16.4 WOW cover plate replacements by the operator

In the context of the investigation, the replacement of damaged WOW cover plates in the aviation operator's Dash-8 fleet were studied. All incidents were recorded in the corresponding maintenance files.

The following table 1 illustrates the replacement of WOW cover plates in the period from 24 November 2009 to the day of the accident. In 3 cases, the reason for replacement was *"found cracked,* in the remaining 12 cases *"found broken"*.

Aircraft	Number of cycles until WOW cover plate replacement; in parentheses whether it was a PMA-part or an OEM-part.	*1)
9A-CQA	4040 (OEM) / 5254 (OEM)	4647
9A-CQB	3842 (OEM) / 7039 (OEM)	5440
9A-CQC	3692 (OEM) / 4148 (OEM) / 387 (OEM) / 448 (OEM) / 781 (OEM) 186 (PMA) / 66 (OEM) / 593 (OEM) / 272 (PMA)	1175
9A-CQD	7866 (OEM)	7866
9A-CQE	6570 (OEM)	6570
9A-CQF	none	

Table 1: *1) Average number of cycles until WOW cover plate replacement
The WOW cover plate on the 9A-CQC aircraft involved in the accident was last replaced before the accident on 20 August 2013 after 593 cycles. At the time of the accident, the new WOW cover plate had accumulated 272 cycles.

Due to the accident, an inspection was performed between first and third October 2013 and on all other Q-400 aircraft of the operator, the WOW cover plates were replaced with the reason *„found broken"*.

The following table 2 illustrates the replacement of WOW cover plates in the period from the accident up to 23 March 2015. In 2 cases, the reason for replacement was *"found cracked,* in 3 cases *„cracked"* and in the remaining 15 cases *"found broken"*.

Aircraft	Number of cycles until WOW cover plate replacement; in parentheses whether it was a PMA-part or an OEM-part.	*1)
9A-CQA	3831 (OEM) / 2118 (PMA)	2974
9A-CQB	2256 (OEM) / 2303 (PMA) / 686 (OEM) / 500 (OEM)	1436
9A-CQC	677 (OEM) / 2173 (OEM) / 334 (OEM)	1061
9A-CQD	3096 (OEM) / 1802 (PMA) / 713 (OEM)	1870
9A-CQE	2051 (PMA) / 2114 (PMA) / 1404 (OEM)	1856
9A-CQF	8782 (OEM) / 2415 (PMA) / 219 (OEM) / 210 (OEM) / 691(OEM)	2463

Table 2: *1) Average number of cycles until WOW cover plate replacement

1.17 Organisational and management information

1.17.1 Operator Croatia Airlines

1.17.1.1 General

In 1990, the operator Croatia Airlines succeeded the former Zagreb Airlines and in 1991 made its first passenger flight using a McDonnell Douglas MD-82. After a brief interruption, the operator began international operations in 1992 with three Boeing 737 aircraft and became a member of the International Air Transport Association (IATA).

The operator has since grown continuously: in 2012 it transported almost two million passengers and at the time of the accident it operated a fleet of two Airbus A320s, four Airbus A319s and six Bombardier Dash-8 Q400s, including the 9A-CQC aircraft which was involved in the accident.

1.17.1.2 Procedures for the crews

1.17.1.2.1 General

The procedures for the operation of the aircraft are specified in the relevant manuals. The general procedures can be found in the operator's operations manual (OM) A. The aircraft-specific procedures can be found in the OM B, which in the present case corresponds to the aircraft manufacturer's aeroplane operating manual (AOM), whereby the operator has also published its own procedures in this AOM. These can be recognised by the fact that these sheets are turquoise rather than white.

In addition, the crews have checklists for normal, abnormal and emergency situations, known as the quick reference handbook (QRH). This assists pilots trained on the aircraft in the performance of the required procedures. The same procedures can also be found in the AOM, but they are listed there with more detailed information.

For the cabin crew, the operator has also published its own Cabin Safety Procedures Manual (CSPM). This provides the fundamentals and is based on the corresponding OM A, B, and D.

1.17.1.2.2 General procedures

Chapter 01.04 of the OM A stipulates amongst others the following regarding the competences, duties and tasks:

„The Commander has the authority and responsibility to declare an emergency situation, whenever deemed necessary.

(…)

In emergency situations, the Commander is authorised to follow any course of action deemed necessary in the interests of safety. He may, in such situations, deviate from prescribed methods, procedures or Minima to the extent required by considerations of safety."

1.17.1.2.3 Procedures for flight crews in abnormal situations

Chapter 08.03.15 H Emergency Procedures of the OM A summarises the main points relating to emergency situations. This also refers to the „Croatia Airlines Cabin Safety Procedure Manual" (CSPM) (cf. chapter 1.17.1.2.4).

H3 stipulates the following in relation to a controlled disembarkation as performed by the crew of the CTN 464 [bold in the original]:

„There may be incidents after which PAX [*passengers*] *have to leave the A/C immediately as a precaution (e.g. obvious bomb alert, annoying smell / smoke in the cabin). Such a case should be described as a controlled disembarkation, even if slides*[5] *are used in lack of PAX stairs (Jet Bridge). It should be taken in consideration to deploy only a minimum number of slides in order to continue the flight.*

The Commander will inform the PAX about the individual situation and nominates the exits to be used. ***Controlled disembarkation is not a time critical situation.***

The purser will inform the PAX about manner how to perform controlled disembarkation. The PAX have to be informed if hand luggage shall remain on board or shoes shall be taken off.

Controlled disembarkation via stairs (Jet Bridge):

- *PAX can take all handluggage along*
- *shoes on*

Controlled disembarkation via slides:

- *no handluggage*
- *no shoes*
- *sit down and slide (do not jump into slide)*

The command to initiate disembarkation as mentioned above should be:

„Controlled disembarkation using exit(s) – by slides / stairs!"

Procedures:

1. *all C/A should stand near their assigned exits and command PAX, as necessary. For example:*
   „Use forward door"
   „Use forward and AFT door"
   „Come this way"
2. *be prepared to arm and open all usable exits, if necessary*
3. *when assessing conditions, be alert to any ground equipment that could present a hazard to the evacuating of PAX*
4. *do not leave disarmed doors unattended while PAX are disembarking"*

H4 stipulates amongst others the following for an *„evacuation after emergency landing": „The evacuation has to be considered as a most risky procedure and therefore should be carried out only if definitely necessary."*

[5] The DHC-8-402 aircraft is not equipped with slides

Chapter 3, Item 3.0.1.2 *Crew Co-ordination During Emergencies* of the operator's AOM stipulates amongst others the following regarding cooperation in the cockpit in abnormal and emergency situations:

„In the event of an abnormal situation, the primary objective of the flight crew is to control the aeroplane. The crew will assess the problem, when vertical and lateral flight path control is established and ground contact is no longer a threat aircraft is generally above 400 FT AGL or above. Once the nature of the problem has been established, the PF will call for the appropriate check list if applicable. For check list with memory items and when the memory items are complete, the PNF will read appropriate emergency checklist (including memory items). The PNF actions the checklist items using the „read and do" method. After take-off or during go-around do not forget to select landing gear up.

***Note:** The PIC may consider leaving the landing gear extended, if performance permits, in cases of hydraulic, engine fire or in cases of structural damage.*

Task Sharing

Whenever the situation and A/C status permits, the PF and PNF should initially remain with their designated duties."

Item 3.0.1.3 *Communication Flight Deck and Cabin Crew* states amongst others the following regarding communication in such a case:

*„The CM-*1 [commander] *will normally handle all communications with the cabin crew.*

For normal communication use the CALL button to contact the cabin crew. The Senior Cabin Crew Member will come to the flight deck or respond on the interphone.

During emergency situations, standardized communication between the Pilots and the Cabin Crew Member(s) is essential. The following is a list of the standard communications to be used during emergency operations.

Table 1: Pilot/Cabin Crew Communications

Action required	***Signal***
Notify cabin crew of an emergency	*PA: **„PURSER TO THE COCKPIT, PLEASE"** Alternate: Emergency Lights ON*
(...)	*(...)*
Passengers to brace prior to an emergency landing (This call should be made approximately 30 sec. prior to landing.)	*PA: **„SAFETY POSITION"** Alternate: More than 3 chimes.*
(...)	*(...)"*

Furthermore, the alternate procedure for extending the landing gear using the alternate release handle is published in the quick reference handbook (QRH) (cf. Annex 3) and in the aeroplane operating manual (AOM) (cf. Annex 4).

1.17.1.2.4 Procedures for cabin crews in abnormal situations

Chapter 4.3.3 of the CSPM stipulates the same text for both the cabin crew and flight crew in relation to controlled disembarkation. Chapter 4.4 *Crew Co-ordination* also stipulates the following:

„CABIN PREPARATION PROCEDURE

*Upon the call **„Purser to the cockpit!"** the purser shall enter the cockpit immediately.*

The Commander shall inform the purser about:

1. kind of emergency, kind and risk of the landing
2. time available for the cabin preparation
3. possible reseating of the PAX (danger areas; A/C trim)
4. The purser shall inform CAs about the situation.

The command to cabin crew and PAX to take the safety position is:

„Safety position, safety position!"

and is given from the cockpit via PA system 30 seconds before touch down."

Chapter 4.8 *SAFETY POSITIONS* of the CSPM describes in detail safety positions for individual groups such as large, small, older and younger passengers, children and pregnant women and how the cabin crew are to instruct passengers.

Chapter 2.C.15 *Mass, Balance and Re-Seating of Passengers,* Item 5 *Re-Seating of Passengers and Cabin Zones* of the CSPM stipulates the following regarding the re-seating of passengers in the Dash-8 aircraft (see Item 3 above in *Cabin Preparation Procedure*):

a) On Commanders request, it might be necessary to re-seat passengers along the aircraft cabin, both in normal and in emergency situations.
b) Table shows zones in CTN aircraft:

AIRCRAFT	***CABIN ZONES (SEAT ROWS)***				
	0A	***0B***	***0C***	***0D***	***0E***
DASH8	*1-4*	*5-8*	*9-12*	*14-17*	*18-21*

According to the statement of the cabin crew, able-bodied passengers were selected and assigned to appropriate seating positions to help in the event of an evacuation with regard to the imminent landing. Chapter 4.7 *Assistance of Pre-Selected Persons* (PSPs) of the CSPM stipulates amongst others the following:

„PSPs are the passengers who will assist in the evacuation. They are expected to act predictably (crew members travelling as passengers, military personnel, someone who is physically and mentally able).

They must be willing to help and prepared to undertake this responsibility and receive a verbal acknowledgement.

There are two main types of PSPs:

Type 1: those who are seated next to an emergency exit and who will be briefed by CA on how best to assist in an evacuation.

Type 2: those selected to help other PAX needing assistance during an evacuation (disabled PAX, PRM, UM, mothers with small children, elderly PAX, etc.).

PSPs must be positioned at all emergency exits (3 or 2 per exits) and briefed accordingly. One PSP will be briefed on operating the exit. Other PSPs will be briefed to block the PAX until the exit is usable and afterwards help them by the exit."

Chapter 10.4.3 *Pre-Selected Passengers* (PSP) *Recruitment Principles* of the CSPM stipulates additionally the following for the DHC-8 Q400 aircraft type:

„Ask two able bodied passengers per exit to take place in the nearest seat rows (if somebody declines this request, do not insist and choose another one). Inform these PSPs how to open the exits and how to help during the evacuation."

1.17.1.2.5 Aircraft-specific procedures

As mentioned in chapter 1.17.1.2.1, the aircraft-specific procedures can be found in the OM B and correspond to the AOM of the aircraft manufacturer; these have

been supplemented with additional turquoise pages by the operator. As a result, only those procedures are described which were of importance to the crew in the accident which is the subject of the investigation.

Chapter 3.1.11 *LANDING GEAR* explains that the alternate procedure to extend the landing gear must be applied if a trouble occurs while retracting or extending the landing gear (cf. Annex 4). The same procedure can also be found in the corresponding checklist in the quick reference handbook (QRH), which the crew uses in normal, abnormal and emergency situations (cf. chapter 1.17.1.2.1 and Annex 3).

OM B chapter 3.0 *ABNORMAL AND EMERGENCY PROCEDURES*, Section 3.1.5 *EMERGENCY LANDING/DITCHING, FORCED LANDING, EMERGENCY EVACUATION* describes the individual procedures. It distinguishes between gear retracted and gear extended. It does not address partial gear extended.

The operator has published additional procedures which are not featured in the QRH in OM B chapter 3.4.4 "*Safety of Flight Supplement, Abnormal and Emergency Checklists*". Chapter 3.4.4.5 *"Landing Gear Failures"* gives indications with regard to how to proceed if a landing must be made which may lead to an emergency situation. Furthermore it stipulates that if an error occurs during extension or retraction of the landing gear, the alternate procedure should be applied in order to extend the landing gear. Normal cycling is neither recommended nor endorsed:

„Cycling the landing gear as an intermediate step to achieve an all gear down and locked indication is not approved or recommended.
As the root cause of the landing gear anomaly is unlikely to be known, cycling the landing gear may create a more difficult landing gear configuration for the flight crew to manage."

If the alternate procedure is not successful, it stipulates configuration options with the appropriate procedures for landing. In the case of the accident which is the subject of the investigation, the operator had published a procedure for the initial situation *"Nose Gear - UP; Main Gear DOWN and LOCKED"* (cf. Annex 5), which is identical to that published by the aircraft manufacturer in its flight operations service letter (FOSL) of 21 April 2011 (cf. chapter 1.17.3 and Annex 6).

The commander further requested that the crew continue to work through the emergency landing checklist. The procedure is published in chapter 3.1.5.1 of the AOM and the QRH respectively (cf. Annex 7).

1.17.2 Aircraft manufacturer

In relation to the problems during extension and retraction of the landing gear, the aircraft manufacturer Bombardier published a flight operations service letter (FOSL; DH8-400-SL-32-031A of 21 April 2011) for all aircraft operators with the following purpose:

„The following FOSL was created to remind Flight Crew of the appropriate procedures for operating the landing gear utilizing the normal or alternate extension systems. Responding to Operator's requests, this FOSL is intended to provide possible considerations for Flight Crew if confronted with an abnormal landing gear configuration, which cannot be rectified with the existing Aircraft Flight Manual (AFM) procedures established within the scope of certification requirements."

„Normal extension / retraction" in the FOSL stipulates amongst others the following:

„(...) If the landing gear fails to extend or retract, assuming that the Normal Extension/Retraction procedures have been actioned correctly, the following list contains known conditions that have presented the Flight Crew with an abnormal landing gear configuration: (...)"

With regard to the alternate procedure The FOSL stipulates introductorily the following:

„For all Dash 8 Series, unless covered by a specific procedure in the AFM, following a landing gear retraction or extension malfunction, the landing gear must be extended using the Alternate Landing Gear Extension procedure (…).

Cycling the landing gear as an intermediate step to achieve an all gear down and locked indication is not approved or recommended. As the root cause of the landing gear anomaly is unlikely to be known, cycling the landing gear may create a more difficult landing gear configuration for the flight crew to manage.

The Alternate Extension procedure was created to provide a backup means of extending the landing gear based on a standard set of common mode failures required for certification. Multiple system failures, compounding failures, structural failures and/or the introduction of foreign objects are not part of, nor required for showing certification compliance."

The FOSL also stipulates the following with regards to the procedure:

„When using the Alternate Extension procedure, Flight Crews must ensure:

- *(...)*
- *The main and nose landing gear release handles are pulled with sufficient force (may exceed 90 lbs) to release the doors and uplocks (pull forces in the air will likely be greater than those experienced on the ground or in a simulator). Continue pulling with whatever force is necessary to achieve release of all landing gear uplocks.*

(...)"

For the specific case of flight CTN 464 it stipulates the following:

„Nose Gear UP, Main Landing Gear Down:

In this situation, if after the Alternate Gear extension procedure has been completed, and it cannot be verified that the nose gear is down and locked by the normal and alternate systems, the Flight Crew must make a decision to either perform a landing with the nose gear not locked, or reset the Alternate Extension system and cycle the landing gear in an attempt to achieve all gear down and locked."

The FOSL presents the crew with a corresponding procedure for both decisions (cf. Annex 6).

1.17.3 Air traffic control

After the crew had declared an emergency and the aircraft was on intermediate approach, air traffic control decided not to clear any further aircraft to take-off or land. The intention was to calm the situation and not risk any other simultaneous emergency. The last clearance for landing on runway 14 before the accident was given at 18:03 UTC, while the last clearance for take-off on runway 28 was given at 18:10 UTC.

From 18:23 UTC, when the fire brigade had reported that it continued to be ready for deployment, air traffic control again allowed aircraft to take-off from runway 28. At 18:29 UTC clearance for the first landing on runway 16 after the accident

was issued. Runway 14 remained closed for the rest of the day (close of operations) for clearance and recovery work.

The wooded area along runway 14 meant that air traffic control had only a limited view of the site of the accident from the control tower. They therefore had to follow events using two closed circuit display systems. Tree clearance conducted later in 2013 resulted in a clear view of runway 14.

1.18 Additional information

1.18.1 Known problems with the nose landing gear on DHC-8 aircraft

Several comparable landings with nose landing gear not extended have been recorded. In an accident in 2007, involving a Q400 series aircraft, the cause was identified as being a coil spring from the operating mechanism of the landing gear doors, which broke off and then jammed in the drag strut from the operating mechanism of the gear doors (cf. Investigation Report 1X001-0/07 of the German Federal Bureau of Aircraft Accident Investigation (BFU) of November 2008). There are no incidents known where a jammed WOW cover plate played a role. The manufacturer emphasizes that this information is only related to OEM-parts.

1.18.2 Known problems with WOW cover plates

According to the landing gear manufacturer, cracks are known to form in the WOW cover plates where they are mounted. The manufacturer stated that cracks can typically be observed on one or both of the upper lugs after a few thousand cycles. After repairing the WOW cover plate in this area using an additional riveted cover plate (doubler), cracks can form on the lower lugs after a further several thousand cycles. In this case, the WOW cover plate must be replaced in the absence of an appropriate repair procedure. In at least one case, the upper and lower lugs failed at the same time.

The WOW cover plate is situated immediately above the NLG tow fitting. A repetitive impact by the tow bar as the tug is being connected to the aircraft is likely possible. Respective traces have been observed in daily operation and are also confirmed by the manufacturer.

1.18.3 Reasons for crack formation on WOW cover plates

After the accident, the aircraft manufacturer conducted an investigation together with the landing gear manufacturer in order to determine the reasons for the known crack formation on WOW cover plates.

The WOW cover plate is mounted via the lower lugs on the inner cylinder of the nose landing gear, while the upper tabs are attached to the thrust collar, which is located between the outer and inner cylinders (see Figure 9). The outer cylinder is fixed, while the inner cylinder can be rotated relative to the outer cylinder in order to allow nose landing gear steering.

During the investigation it could be proven that, based on manufacturing tolerances of the components and friction, a residual rotation of up to 3° is possible between the thrust collar, which rotates together with the inner cylinder, and the inner cylinder, when operating the nose landing gear steering. This type of mounting means that this residual rotation can lead to lateral forces on the WOW cover plate.

Per design, the WOW cover plate is not firmly connected with the inner cylinder via the lower lugs. A certain amount of lateral freedom is provided. However, the existing clearance is not large enough to absorb the residual rotation completely. This can cause the WOW cover plate to come into contact with adjacent parts of

the landing gear, which can lead to mechanical stress in the upper and lower lugs.

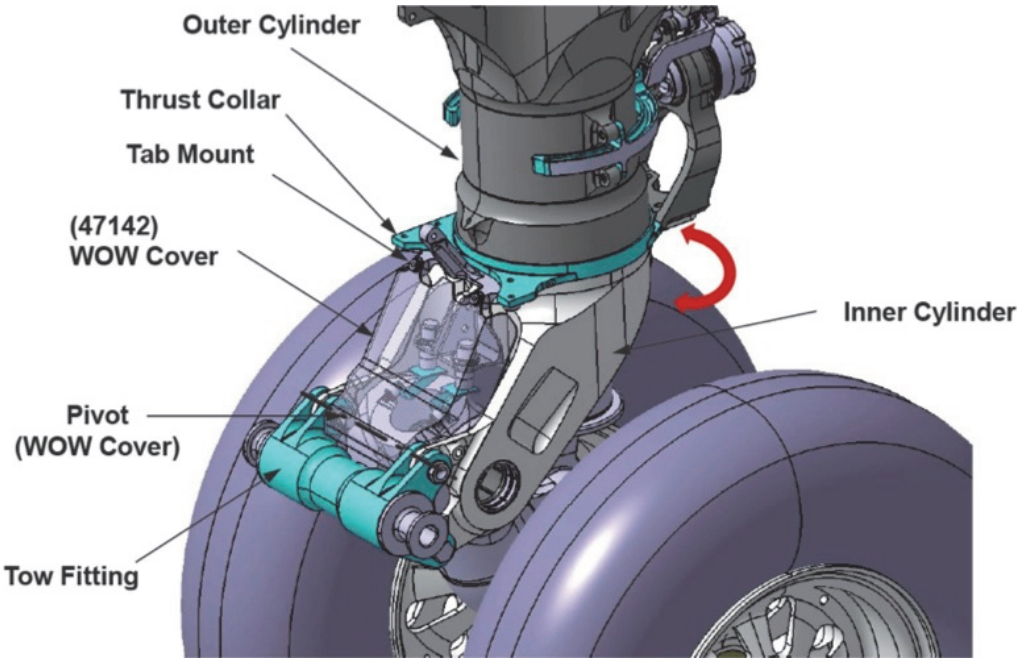


Figure 9: WOW cover plate mounting assembly
(Image from the gear manufacturer, adapted by the STSB)

Using a computer simulation, it was also possible to prove that the resulting stress on the upper lugs is generally greater than that on the lower lugs. The main stress points in the area of the upper and lower lugs determined in this manner were also at the points where the WOW cover plates actually failed in operation. On the lower lugs this was in the area of the welding seams (see Figure 10).

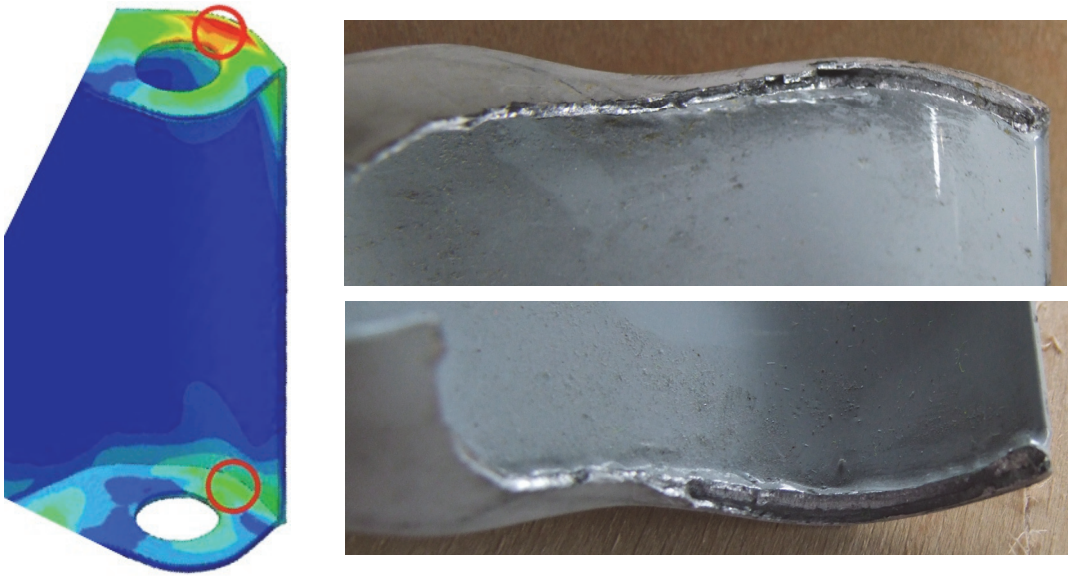


Figure 10: Left: View from below onto the WOW cover plate in a simulation. The red circles show the simulated stress concentration in the area of the lower lugs (image from the gear manufacturer, adapted by the STSB).
Right: WOW cover plate from aircraft 9A-CQC after the accident. The lower lugs are broken at the welding seams.

1.19 Useful or effective investigation techniques

None.

2 Analysis

2.1 Technical aspects

2.1.1 Extension of the nose landing gear

Despite repeated attempts, the flight crew was not successful in extending the nose landing gear using the normal or alternate procedures. The checklist for the alternate procedure (cf. Annex 3) explicitly states that the force to be applied on the release handle can be up to 41 kg (approximately 400 N). The FOSL, which the crew also consulted, stipulates that it may be necessary to apply an even greater force and that the necessary forces in the air are probably greater than those on the ground or in a simulator. In view of this evidence it can be assumed that the crew attempted to extend the nose landing gear with the maximum force they could apply. Since there is no evidence that the crew made errors in applying the procedure, it can be concluded that it was not possible to extend the nose landing gear due to a technical fault.

On the ground, after the landing with retracted nose landing gear, it was possible to extend the nose landing gear using the alternate procedure by applying a force of 543 N, corresponding to 55 kg (122 lb), on the release handle. This is significantly higher than the aforementioned maximum force of 41 kg (90 lb; approximately 400 N) according to the checklist. After the damaged WOW cover plate was identified and removed, it was possible to extend the nose landing gear using the alternate procedure with a force of 334 N on the release handle; extending and retracting the nose landing gear using the normal procedure also functioned smoothly. These findings lead to the conclusion that on the ground after the landing, the damaged WOW cover plate, which had been bent upwards, prevented the extension of the nose landing gear to the extent that the force required on the release handle increased significantly compared to the normal state.

Taking into account the fact that according to the FOSL the required forces in the air are probably greater than those on the ground, it seems plausible that the jammed WOW cover plate meant the force required to extend the nose landing gear during the flight was so great that it could not be applied either by the hydraulic system using the normal procedure or by the crew using the alternate procedure. Furthermore, the damage in the region of the nose landing gear wheelwell may mean that the situation on the ground after the landing with retracted nose landing gear was no longer identical to that in the air and that comparisons are therefore of limited value.

The construction of the landing gear means that the drag strut must move downwards by approximately 0.4 mm while unlocking the landing gear in order to overcome the dead point. If this minor movement is not possible, e.g. due to a mechanical blockage, it is not possible to extend the landing gear. In the present case, the jammed WOW cover plate constituted such a mechanical blockage.

The WOW cover plate trapped in the nose wheel mechanism therefore prevented the unlocking and extension of the nose landing gear during the flight.

2.1.2 Failure of the WOW cover plate

The EMPA investigation of the WOW cover plate and five other WOW cover plates which had been discarded due to cracks on the upper lugs, revealed defects in the welds in the lower lugs. These defects originated when the WOW cover plates were manufactured and are the reason for the formation of fatigue cracks, which in this case ultimately led to fracturing of the lower lugs.

The formations of cracks on the WOW cover plates, primarily in the area of the upper, but also the lower lugs, had been known for a considerable time. To what extent damages caused by contact with tow bars had an impact cannot be evaluated conclusively.

The joint investigation by the aircraft manufacturer and the landing gear manufacturer revealed that the design of the WOW cover plate mounting means that rotation of the thrust collar inside the inner cylinder when operating the nose landing gear steering can lead to lateral forces on the WOW cover plate. These lateral forces can create mechanical stress in the area of the upper and lower WOW cover plate lugs.

These investigations strongly suggest that the way the WOW cover plates are mounted means they are subjected to undesirable lateral forces when the nose landing gear steering is operated. Over many cycles or operations of the nose landing gear steering these lateral forces can cause the formation of fatigue cracks, making it finally possible for the lugs to fracture. The evidence of the joint investigation by the aircraft manufacturer and the landing gear manufacturer suggests that failure first occurs in the area around the upper lug; this has also been the main observation in practice.

The fact that in the present case the lower lugs fractured first can be explained by the weld defects on the lower lugs identified by the EMPA. This fracture must have happened before the gear was retracted after take off in Zagreb. Subsequently the WOW cover plate was much probably bent upwards by airstream and got finally trapped in the nose gear mechanism while retracting the gear.

This raises two issues: Firstly that of the manufacturing quality of the WOW cover plates and the required standards and verification of these. According to the EMPA report (cf. chapter 1.16.2 and 1.16.3) there is a tendency of having a lower quality on PMA-parts. However, according to the tables 1 and 2 in chapter 1.16.4, there seems to be no statistical evidence of a significant difference between PMA- or OEM-parts with regard to failure rates. Secondly, it is obvious that mounting the WOW cover plate on two different components which are subjected to a certain amount of mutual rotation leads to undesirable lateral forces. This can lead to failure of the lugs even in the case of WOW cover plates which have no weld defects, which is why attention should be devoted firstly to the design of the WOW cover plate mounting, and only then should the manufacturing quality be considered.

It is surprising in this context that the 9A-CQC aircraft which was involved in the accident, had to change each of the WOW cover plates after approximately one thousand cycles (cf. chapter 1.16.4), significantly more often than on the operator's other Q400 aircraft and far less than the several thousand cycles described by the landing gear manufacturer (see chapter 1.18.2). It is reasonable to conclude that at least in this aircraft, the above mentioned lateral forces were considerably greater than was usually the case.

2.2 Human and operational aspects

2.2.1 Operator

The documents published by the operator are consistent with those published by the aircraft manufacturer. The additional procedures published for the cockpit and cabin crews gave the crew the necessary information regarding how to proceed and cooperate in abnormal and emergency situations.

In the published procedures for an emergency landing in the quick reference handbook (QRH) the circuit breaker (CB) to be pulled is designated as *„GPWS CB (A1 - Avionics CB Panel)"*. In the aircraft AOM this CB panel is designated as

the *„Avionics Circuit Breaker Panel"* at the corresponding position. On the aircraft itself, there is no designation of the CB panels. Furthermore the A1 position can be found on several CB panels. The flight crew first found a CB in the A1 position which was marked *„pass brief sys"*. This was on a CB panel immediately below the *„Avionics Circuit Breaker Panel"* and was designated as the *„Left DC Circuit Breaker Panel"* in the AOM. Furthermore, the CB which the crew found after further searching was marked EGPWS, as the 9A-CQC aircraft, like all of Croatian Airlines' Dash-8s, was equipped with an enhanced ground proximity warning system (EGPWS).

This unclear information kept the crew occupied for approximately four minutes until finally they intuitively pulled the correct CB. In terms of flight safety it must be stated that information, which must be used in an emergency situation and therefore under time pressure, should not lead to uncertainty due to incoherence as it happened in the present case.

The alternate landing gear extension procedure in the QRH did not contain any information as to how to proceed in the event that it was not successful. The FOSL offers corresponding procedures. It was therefore appropriate that the operator had adopted these procedures in its OM B. However, the fact that these procedures or at least a corresponding reference to them is not published in the QRH is not particularly user-friendly.

2.2.2 Flight crew

When the flight crew noted during the first approach that the landing gear display did not correspond to a fully extended and locked landing gear, they immediately decided to abort the approach. This behaviour was safety conscious.

After a short discussion, the flight crew then decided to retract the landing gear again due to the unusual noise. The cockpit conversations indicate that the two pilots' cooperation was optimal according to the principles of CRM[6]. This was continued throughout the remainder of the flight.

After the crew had decided to enter a holding pattern, the commander decided to devote himself exclusively to piloting for the time being and to troubleshoot the fault only when in the holding pattern. This decision was appropriate to the situation.

The subsequent discussion among the crew regarding alternate landing sites and fuel reserves is proof of a comprehensive situational assessment.

After the copilot had begun to work through the alternate landing gear extension checklist after entering the holding pattern, the commander decided to extend the landing gear normally once again, i.e. using the landing gear lever. This decision had no consequences in the present case, but did not correspond to the FOSL published by the aircraft manufacturer. This states that an attempt must first be made to extend the landing gear using the alternate procedure. Only if this procedure is not successful may another attempt to retract and extend the landing gear be made using the landing gear lever.

The fact that the crew used the aircraft manufacturer's FOSL after the unsuccessful alternate extension of the landing gear indicates good background

[6] CRM: Crew resource management. CRM was developed as training for flight crews based on the experience of numerous accidents in which a lack of cooperation in the cockpit was a causal factor. CRM is designed to raise awareness of the fact that on board an aircraft not only technical understanding, but also the interpersonal domain are decisive factors for the safe conduct of flights.

knowledge. The crew therefore exhausted all opportunities to correct the fault offered by the documentation in relation to the problem.

After several unsuccessful attempts to extend the landing gear, the crew finally decided on a landing with the nose landing gear retracted. The subsequent information to the cabin crew was comprehensive and the inclusion of all crew members in the decisions taken was prudent and safety conscious. The subsequent declaration of an emergency and the information given to air traffic control were appropriate to the situation and allowed air traffic control to make the necessary preparations.

Based on his situational assessment, the commander recognised the option of a controlled disembarkation after the aircraft had come to a standstill. The emergency landing checklist provides for an evacuation after the landing. Based on the situation the commander decided in deviation from the checklist, not to do so after landing. This is also in accordance with the procedures stipulated by the operator: the OM A explicitly states that an evacuation is a highly risky procedure and should only be used if there is no other solution (cf. chapter 1.17.1.2.1).

In the same manner the commander also decided during the approach not to dump the cabin pressure and not to switch on the emergency transmitter. In an emergency, the crew always has the option of deviating from a checklist if it is required for safety reasons.

As the copilot reported *„cabin crew prepare for landing"* via the public address system just before landing he did not use the phraseology stipulated in the documentation for such a case: *„safety position, safety position!"* However, this had no effect on the cabin crew, who also understood that the landing was imminent and informed the passengers accordingly.

The cockpit conversations indicate that the crew were intensively concentrating on the imminent landing. The information given by the copilot to the commander during the touchdown procedure and the subsequent landing roll on the main landing gear regarding pitch and speed helped to successfully perform the landing with retracted nose landing gear.

The crew's actions after the aircraft came to a standstill, such as shutting down the engines and communicating with the fire brigade via aerodrome control, demonstrate prudence and were appropriate to the situation.

In summary, it can be stated that everyone cooperated calmly and optimally, which helped to defuse the situation.

2.2.3 Cabin crew

The cabin crew worked according to the procedures stipulated in the relevant documentation of the operator. They implemented the instructions of the cockpit crew in a timely manner and informed the cockpit crew regarding each completed measure.

The cabin crew's professional behaviour made a significant contribution to the fact that the passengers remained calm and were able to disembark the aircraft in an orderly manner after the aircraft came to a standstill on the runway.

2.2.4 Air traffic control

Air traffic control assisted the flight crew from the outset and supported them with instructions and information. They also kept the frequency free for the flight crew, which allowed unrestricted contact. The decision to suspend all approaches and

departures during the period in which CTN 464 was on its final approach was prudent.

The coordination conversations with the fire brigade indicated foresight and allowed for optimum use of its resources.

The proactive and comprehensive support of air traffic control contributed to the creation of the optimum conditions for the flight crew to perform troubleshooting, the approach, landing and the subsequent controlled disembarkation.

The fact that the view from the control tower of part of runway 14 was restricted constituted a risk. It would therefore not always have been possible to identify any unexpected emergencies on runway 14. Tree clearance conducted later in 2013 resulted in an unobstructed view of runway 14.

2.2.5 Aircraft manufacturer

The flight operations service letter (FOSL) published by the aircraft manufacturer provides detailed information as to how to proceed with partial gear extension and is designed to support the crew. However, this information is not part of a checklist and does not have to be memorised by the crew.

It should be noted that the instruction in the FOSL *„Cycling the landing gear as an intermediate step to achieve an all gear down and locked indication is not approved or recommended (...)"* initially appears contradictory, because some time later the decision is left to the crew as to whether and how often they wish to retract and extend the landing gear using the landing gear lever: *„(…) the Flight Crew must make a decision to either perform a landing with the nose gear not locked, or reset the Alternate Extension system and cycle the landing gear in an attempt to achieve all gear down and locked."*

Only the expression *„as an intermediate step"* refers to the fact that the alternate landing gear extension procedure must be applied before any possible extension or retraction of the landing gear can be done using the gear lever. This may also have contributed to the fact that the commander requested extending and retracting the landing gear using the landing gear lever without first having used the alternate procedure.

The alternate landing gear extension procedure in the QRH, published by the aircraft manufacturer, did not contain any information as to how to proceed in the event that it was not successful. Respective procedures are published by the aircraft manufacturer in the FOSL but the fact that these procedures or at least a corresponding reference to them is not published in the QRH is not particularly user-friendly.

It should be noted that it had been necessary to change the WOW cover plates relatively frequently due to crack formation in the area around the lugs. Only the manufacturer's clarification after the present accident made it clear that unforeseen loading of this component with lateral forces had led to a rapid deterioration of the WOW cover plates.

3 Conclusions

3.1 Findings

3.1.1 Technical aspects

- The aircraft was licensed for VFR and IFR transport.
- Both the mass and centre of gravity of the aircraft at the time of the accident were within the permitted limits according to the AFM.
- The WOW cover plate of the nose landing gear was found trapped in the nose landing gear mechanism.
- The WOW cover plate was cracked on the lower left and right lugs and was bent upwards.
- After the damaged WOW cover plate was removed, it was possible to easily and repeatedly extend and retract the nose landing gear using the normal and the alternate extension procedure several times.
- The WOW cover plate was a PMA-part.
- The investigation of the WOW cover plate and five identical WOW cover plates revealed weld defects in the area of the lower lugs. These had occurred during the manufacture of the WOW cover plates.
- These defects led to the formation of fatigue cracks.
- The joint investigation of the aircraft manufacturer and the landing gear manufacturer revealed that the design of the mounting means that rotation of the thrust collar against the inner cylinder when operating the nose landing gear steering can lead to lateral forces on the WOW cover plate.
- These lateral forces may lead to mechanical stress in the area of the upper and lower WOW cover plate lugs.
- This stress led to fatigue cracks in the lugs of the WOW cover plate.

3.1.2 Crew

- The pilots were in possession of the necessary licences for the flight.
- There are no indications of the pilots suffering health problems during the flight involved in the accident.

3.1.3 History of the flight

- During the final approach on runway 14 at Zurich Airport (LSZH) it was not possible to extend the nose landing gear.
- The flight crew aborted the approach and received clearance to enter the AMIKI holding pattern to perform troubleshooting.
- The flight crew was not successful in extending the nose landing gear using the alternate landing gear extension checklist in the quick reference handbook (QRH), or the notes included in the aircraft manufacturer's flight operations service letter (FOSL) to the aircraft operator.
- The flight crew decided on a landing with the main landing gear extended and the nose landing gear retracted.
- The passengers were informed and the cabin was prepared for an emergency landing.

- Air traffic control was informed accordingly and the fire brigade alerted.
- Shortly before 18:18 UTC, the aircraft touched down on runway 14 on its main landing gear, approximately 450 m after the runway threshold. After approximately 1000 m, the nose made contact with the runway surface and the aircraft came to a standstill after another 540 m.
- Fire did not break out. The fire brigade was ready to intervene.
- The passengers and crew disembarked the aircraft via the front left cabin door according to the procedure *„controlled disembarkation"*.
- No passengers or crew members were injured.
- The underside of the forward fuselage section of the aircraft was damaged.

3.1.4 General conditions

- The weather conditions had no influence on the accident.
- It had been known for some time that the in the area of the lugs of the WOW cover plate cracks can be formed.
- The wooded area along runway 14 meant that the aerodrome control officer had only a limited view of the site of the accident.

3.2 Causes

The accident is attributable to the fact that the flight crew was not successful in extending the nose landing gear and then had to conduct a landing with extended main landing gear and retracted nose landing gear.

The following factor was identified as the direct cause of the accident:

- The WOW cover plate on the nose landing gear was broken on both lower lugs so that it was bent upwards around the upper tab mounts and was trapped in the nose gear mechanism, which prevented the extension.

The crack on the lower WOW cover plate lug is attributed to the following factors:

- The way the WOW cover plate was mounted led to lateral forces on the WOW cover plate and mechanical stress in the area of the upper and lower lugs during operation of the nose landing gear steering.
- There were weld defects in the area of the lower lugs.

4 Safety recommendations, safety advices and measures taken since the accident

Safety recommendations

According to the provisions of Annex 13 of the International Civil Aviation Organization (ICAO) and Article 17 of Regulation (EU) No. 996/2010 of the European Parliament and of the Council of 20 October 2010 on the investigation and prevention of accidents and incidents in civil aviation and repealing Directive 94/56/EC, all safety recommendations listed in this report are intended for the supervisory authority of the competent state, which must decide on the extent to which these recommendations are to be implemented. Nonetheless, any agency, any establishment and any individual is invited to strive to improve aviation safety in the spirit of the safety recommendations pronounced.

Swiss legislation provides for the following regulation regarding implementation in the *Verordnung über die Sicherheitsuntersuchung von Zwischenfällen im Verkehrswesen* (Ordinance on Transportation Incident Safety Investigations) [VSZV]:

"Art. 48 Safety recommendations

[1] The STSB shall address the safety recommendations to the relevant Federal Office and shall inform the relevant Department of the recommendations. In the event of urgent safety issues, it shall inform the relevant Department immediately. It may make comments on any implementation reports by the Federal Office for the attention of the relevant Department.

[2] The Federal Offices shall inform the STSB and the relevant Department periodically regarding the implementation of the recommendations or the reasons it has dispensed with such measures.

[3] The relevant Department may direct orders for implementation of recommendations to the relevant Federal Office."

The STSB shall publish the answers of the relevant Federal Office or foreign supervisory authorities at www.sust.admin.ch in order to provide an overview of the current implementation status of the relevant safety recommendation.

Safety advices

The STSB may publish safety notes in response to any safety deficit identified during the investigation. Safety notes shall be formulated if a safety recommendation in accordance with Regulation (EU) No. 996/2010 does not appear to be appropriate, is not formally possible, or if the less prescriptive form of a safety guideline is likely to have a greater effect. The legal basis for STSB safety guidelines can be found in Article 56 of the VSZV:

"Art. 56 Information on accident prevention. The STSB may publish relevant general information on accident prevention."

4.1 Safety recommendations

The former Swiss Accident Investigation Board (SAIB) drew up an interim report concerning the accident which is the subject of the investigation. This interim report of 9 October 2013 was approved by the Management Board on 10 October 2013 and then sent to the appropriate authorities in accordance with Article 18, paragraph 2 of the Ordinance on the Investigation of Aircraft Accidents and Serious Incidents.

In this interim report, the SAIB issued the following two safety recommendations:

4.1.1 Safety recommendations regarding WOW cover plates

4.1.1.1 Safety deficit

On 27 September 2013, a scheduled flight with flight plan call sign CTN 464 from Zagreb (Croatia) to Zurich (Switzerland) was conducted using a Bombardier DHC-8-402 aircraft, registration 9A-CQC. After an uneventful flight, the aircraft was established on the localiser and the glide path for an instrument approach on runway 14. The pilots extended the landing gear when at a distance of approximately six nautical miles from the runway threshold. Although the main landing gear could be completely extended, it was not possible to extend the nose landing gear.

The flight crew aborted the approach and air traffic control offered the crew entry into a holding pattern to troubleshoot the fault. It was not possible to extend the nose landing gear any further using the aircraft's non-normal/emergency checklist in the quick reference handbook (QRH), or according to the guidelines published in a flight operations service letter (FOSL) from the aircraft manufacturer to the aircraft operator. The flight crew decided on a landing with the main landing gear extended and the nose landing gear retracted. After the passenger cabin was prepared for an emergency landing and air traffic control was informed of the situation, a second approach was performed.

Shortly before 18:18 UTC, the aircraft touched down on runway 14 on its main landing gear, approximately 450 m after the runway threshold. After approximately 1000 m, the nose made contact with the runway surface and after another 540 m the aircraft came to a standstill.

During the technical inspection of the aircraft it was found that the cover plate which protects the two weight on wheels (WOW) sensors was jammed in the nose landing gear mechanism. Prior to this the WOW cover plate was cracked on the lower left and right lugs and was bent upwards. After the damaged WOW cover plate was removed, it was possible to extend and retract the nose landing gear using the normal and alternate extension procedures. It can therefore be concluded that the WOW cover plate, which was cracked and bent upwards, prevented the DHC-8-402 from extending its nose landing gear.

As it has not yet been possible to prove that the present case should be treated as a one-off case, it is possible that other similar types of nose landing gear may be affected.

4.1.1.2 Safety Recommendation No. 476

Transport Canada and the European Aviation Safety Agency, together with the aircraft and the landing gear manufacturers, should take appropriate measures in order to facilitate early detection of damaged weight on wheel cover plates on nose landing gears in levered suspension configuration.

4.1.1.3 Safety Recommendation No. 477

Transport Canada and the European Aviation Safety Agency, together with the aircraft and the landing gear manufacturers, should assess the risks involved with the installation of weight on wheel cover plates on nose landing gears in levered suspension configuration and take appropriate preventive measures.

4.1.1.4 Comment by Transport Canada

In a supplement to a letter from the Transportation Safety Board of Canada of 28 January 2014, Transport Canada commented on the two safety recommendations as follows:

Regarding Safety Recommendation No. 476:

„Bombardier Aerospace (BA), the aircraft manufacturer conducted a review of the Weight on Wheels (WOW) sensor cover plate installation on the Nose Landing Gear (NLG) of the DHC-8 series aircraft.

Transport Canada has reviewed available in-service data and has communicated with BA and selected Canadian operators of the DHC-8 series aircraft.

Transport Canada's findings are as follows:

- *The DHC-8 100/200/300 series aircraft model, although similar, utilizes a flat plate hinged type WOW sensor cover on the NLG. This construction is not susceptible to the same failure scenario as depicted in the accident aircraft, DHC-8 402. Consequently, it was determined that no further review or research is required of the DHC-8 100/200/300 series.*
- *On October 2, 2013, BA issued an All Operator Message (AOM) No. 581, as noted within the SAIB Interim report, to immediately advise all operators of the DHC-8-400 series aircraft and the preliminary findings of this accident investigation.*
- *Through an In-Service data review it was noted that BA had issued a Repair Drawing (RD) 8/4-32-0217. The RD is a temporary allowance to continue flight operations for a maximum period of 50 flight hours with the WOW sensor cover removed. Included with the RD is a Service Concession Request (SCR) 0055-05, issued by Goodrich, the landing gear manufacture, for a permanent repair to the upper mounting lugs of NLG WOW sensor cover assembly, P/N 47142-1/-3.*

  There is a concern that the upper lugs are being repaired and the cover is returned to service without any examination of the lower lugs for existing cracks.

  BA has recently revised the RD 8/4-32-0217 to issue 2, which requires a Fluorescent Penetrant Inspection (FPI) on the entire part for cracks before any repair to the upper lugs is accomplished.

  It should be noted that the BA Repair Drawing and Goodrich SCR are applicable only to the Original Equipment Manufacturer (OEM) part and not the Part Manufacturing Approval (PMA) part.

  The PMA part is approved under Federal Aviation Administration (FAA) jurisdiction and as such the FAA has been notified.
- *BA conducted a Triage meeting on November 1, 2013. A risk assessment of the available data was completed and the contributing factors were reviewed by BA Engineering Specialists.*
- *Transport Canada reviewed the Triage report and has been in contact with BA to clarify/explain concerns noted. BA is currently proceeding with is investigation/examination of a damaged WOW sensor cover hindering extension of the NLG. Transport Canada is in communication with BA to determine the validity and effectiveness of any corrective action put forth.*
- *On November 13, 2013, Service Letter DH8-400-SL-32-0.37, which has recently been revised to revision A, was issued to provide operators with additional information relevant to the AOM 581. The Service Letter includes the recommendation that the WOW cover be inspected prior to flight.*

Considering the issuance of the BA communications to operator/maintainers of the DHC-8-400 series aircraft, in the form of an All Operators Message, Service Letter and revision of the Repair Drawing, Transport Canada is confident that the risk for another WOW sensor cover hindering extension of the NLG has been adequately mitigated for the short term of the OEM part.

Transport Canada will continue to communicate with BA to determine if additional corrective action is required to further mitigate the relevant risk. Transport Canada will assess any corrective action developed and determine if a Canadian Airworthiness Directive is justified.

Any further progress on the issue will be communicated to the Swiss Accident Investigation Board."

Regarding Safety Recommendation No. 477:

"Bombardier Aerospace (BA), the aircraft manufacturer conducted a review of the Weight on Wheels (WOW) sensor cover plate installation on the Nose Landing Gear (NLG) of the DHC-8 series aircraft.

Transport Canada limited its review of WOW cover plates to similar models as the accident aircraft, specifically the DHC-8-100/200/300 series and the DHC-8-400 series. Results of the review are depicted under Transport Canada's response to Safety recommendation No. 476.

Transport Canada is confident that measures taken have reduced the risk to an acceptable level."

In a letter, dated 5 May 2015 Transport Canada informed Transportation Safety Board of Canada about the following:

„Bombardier Aerospace has since provided Transport Canada with Revision A of the risk assessment (Triage) regarding the Nose Landing Gear (NLG) Weight on Wheel (WOW) Sensor Cover failure. Transport Canada has reviewed the risk assessment and concurs with the risk level for the failure of the NLG WOW cover plate being LOW. As a result, no mandatory corrective action will be issued by Transport Canada regarding the new proposed location for mounting the Original Equipment Manufacturer (OEM) manufactured WOW cover plate described in paragraph 4.2.1 of the attached draft investigation report.

It is important to highlight that the risk assessment conducted by Bombardier Aerospace focused primarily on the OEM manufactured WOW sensor covers and that it cannot be assumed that the results of that risk assessment will be the same as the WOW sensor cover manufactured under the Part Manufacture Approval (PMA). The PMA part is approved under the FAA jurisdiction and as such the FAA has been notified."

4.2 Safety advices

None

4.3 Measures taken since the accident

4.3.1 Aircraft manufacturer

Five days after the accident, on 2 October 2013, the aircraft manufacturer Bombardier sent a message (Bombardier Q400 All Operator Message No. 581) to all operators of Bombardier Q400 aircraft and Bombardier representatives. This message was issued after consultation with the former SAIB and contained the following recommendation:

"Operators are reminded that the proximity cover must be secure prior to flight. Diligence must be taken by ground crew when attaching and removing the tow bar. A tactile inspection of the nose gear WOW cover should be considered as part of the pre-flight inspection."

The aircraft manufacturer announced after the completion of the joint investigation with the landing gear manufacturer (cf. chapter 1.18.3) that a new way of mounting the WOW cover plate is planned. A respective design study is available. The plan is to no longer mount the WOW cover plate directly on the thrust

collar; instead it will be mounted to the inner cylinder using a new type of tab bracket (see Figure 11). This is to prevent unwanted lateral forces being transferred to the WOW cover plate via the nose landing gear steering.

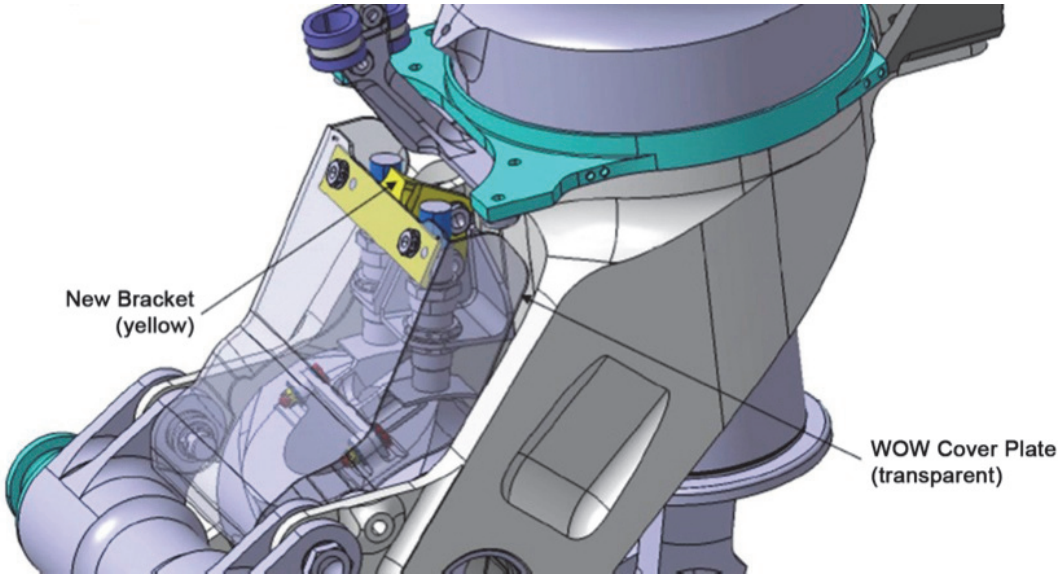


Figure 11: The plan is to no longer mount the WOW cover plate on the thrust collar; instead it will be mounted to the inner cylinder using a new bracket (Image from manufacturer's design study, adapted by the STSB).

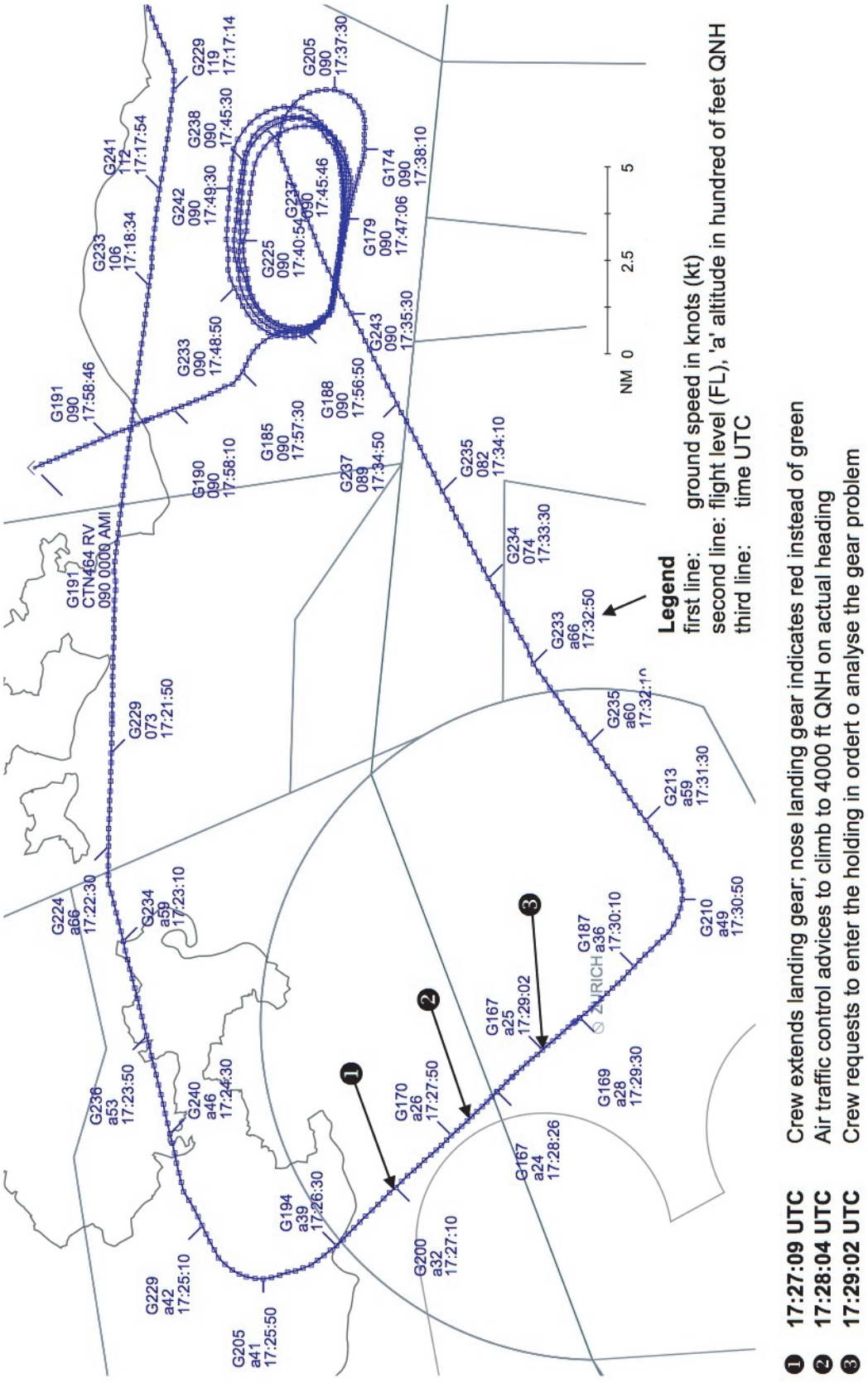
Payerne, 20. August 2015 Investigation Bureau STSB

This final report was approved by the Board of the Swiss Transportation Safety Investigation Board STSB (Art. 10 lit. h of the Ordinance on the Safety Investigation of Transportation Incidents of 17 December 2014).

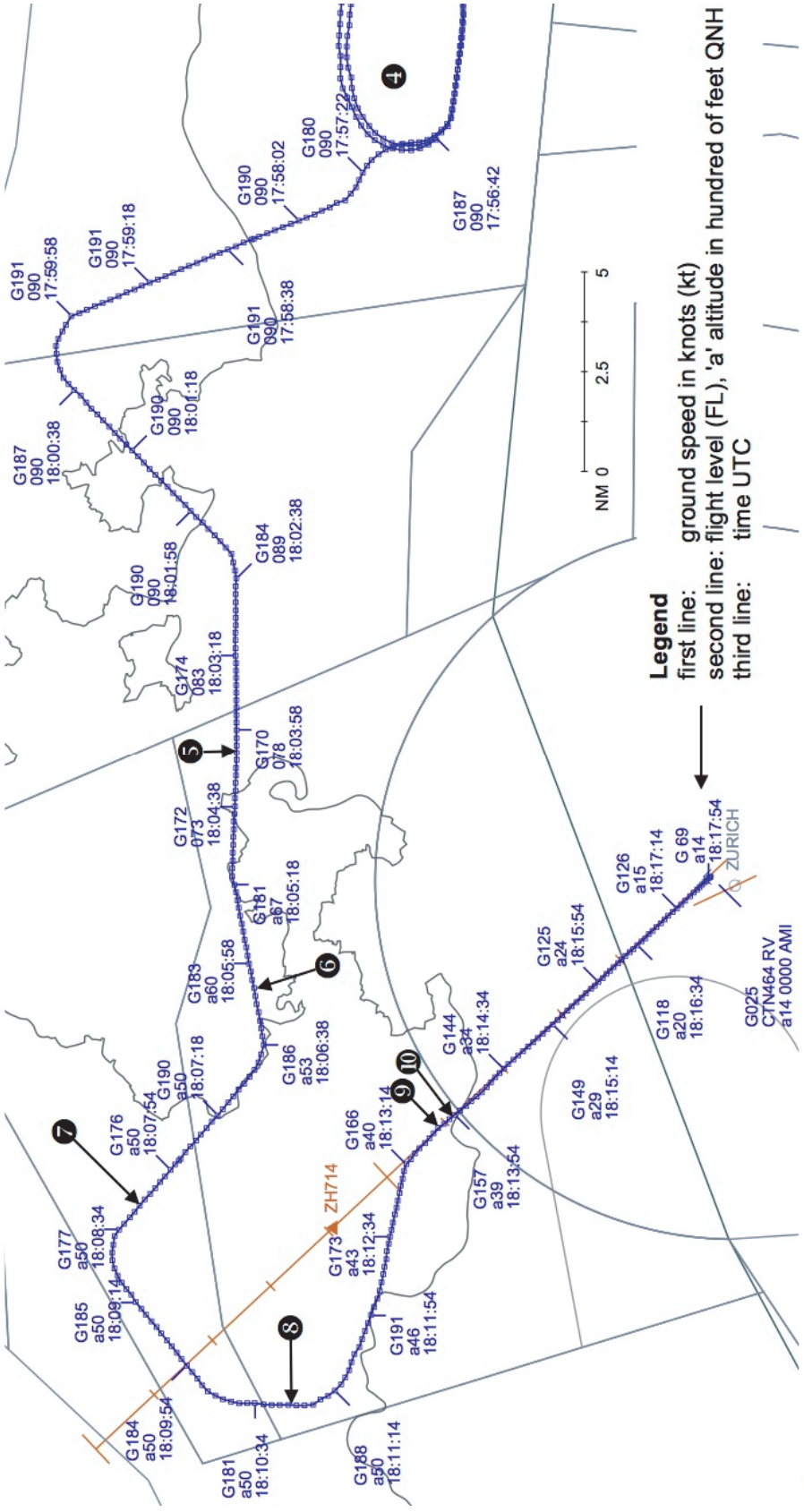
Berne, 13. August 2015

Annexes

Annex 1: Radar recording of the flight path on the first approach and entry into the holding pattern



Annex 2: Radar recording of the flight path on the second approach



Annex 3: Procedure for alternate landing gear extension according to the QRH

ALTERNATE LANDING GEAR EXTENSION or "LDG GEAR INOP" (Caution Light)

(One or more Landing Gear fail to extend)

Landing Considerations:

– Landing Gear cannot be retracted.
– Nosewheel steering will be inoperative.

***Note**: The main and nose gear release handles pull force will be significantly higher than experienced during practice alternate landing gear extensions. The required pull force, to release the gear uplocks, can be as high as 41 kg (90 lb). It may require a repeated pull effort to achieve a landing gear down and locked indication.*

- Airspeed ..... 185 KIAS (max)
- L/G Inhibit switch ..... Inhibit
- Landing Gear selector ..... Down
- Landing Gear Alternate Release door ..... Open
- Main Gear Release handle ..... pull fully down
  Check L & R DOOR amber open and LEFT & RIGHT green locked down advisory lights illuminate.
- Landing Gear Alternate Extension door ..... Open

***Note**: IF LEFT and/or RIGHT green gear locked down Advisory Lights do not illuminate, insert Hydraulic Pump handle in socket and operate until LEFT and RIGHT green gear locked down Advisory Lights illuminate.*

- Nose Gear Release handle ..... pull fully up
  Check N DOOR amber open and NOSE green locked down advisory lights illuminate.

***Note**: Leave Landing Gear Alternate Release and Alternate Extension Doors fully open and L/G Inhibit switch at Inhibit.*

- Gear–Locked–Down indicator ..... On/check/Off
- Anti-Skid ..... Test

After Landing:

As soon as possible after engine shutdown:

- Ground Locks ..... install

Figure 12: Copy of the procedure published in the quick reference handbook (QRH) (PSM 1-84-1B, page 14.3, of 7 May 2013). The black vertical bars on the right margin illustrate what has been changed since the last publication of this procedure.

Annex 4: Procedure for alternate landing gear extension according to the AOM

3.1.11 LANDING GEAR

NOTE: Following any landing gear retraction or extension malfunction not covered by a specific procedure in this section, the landing gear must be extended using the Alternate Landing Gear Extension procedure that follows.

3.1.11.1 ALTERNATE LANDING GEAR EXTENSION or **LDG GEAR INOP (Caution Light)**
(One or **more Landing Gear fail to extend)**

Airspeed ..... 185 KIAS (MAX)

L/G Down Select Inhibit Switch ..... INHIBIT
Lift switch guard and set L/G DOWN SELECT INHIBIT SW, on the co-pilot's flight compartment ceiling, to INHIBIT.

NOTE: If LDG GEAR INOP caution light was out, it will illuminate when the L/G DOWN SELECT INHIBIT SW is selected to INHIBIT.

Landing Gear Selector ..... DN

Landing Gear Alternate Release Door ..... Open Fully
Pull open fully the MAIN LANDING GEAR ALTERNATE RELEASE door, on the flight compartment ceiling.

NOTE: Door must stay fully open after alternate landing gear extension.

Main Gear Release Handle ..... Pull Fully Down
Pull the MAIN LANDING GEAR RELEASE handle fully down
to release main gear door uplocks and main gear.
Check L DOOR and R DOOR amber doors open and
LEFT and RIGHT green locked down advisory lights illuminate.

NOTE: The Main Gear release handle pull force will be significantly higher than experienced during practice alternate landing gear extensions.
The required pull force, to release the Main Gear uplocks, can be as high as **41 kg** (**90 lb**).
It may require a repeated pull effort to achieve a Main Landing Gear down and locked indication.

Landing Gear Alternate Extension Door ..... Open fully
Open fully the LANDING GEAR ALTERNATE EXTENSION door on the flight compartment floor,
aft left of the co-pilot's seat.

NOTE: If LH and / or RH green gear locked advisory lights do not illuminate, insert the Hydraulic Pump handle in the socket and operate pump until LH and RH green advisory lights illuminate.
Door must stay fully open after alternate landing gear extension.

Nose Gear Release Handle ..... Pull Fully Up
Pull the NOSE GEAR RELEASE handle fully up to release nose gear door uplocks and nose gear.
Check N DOOR amber doors open and NOSE green gear locked down advisory lights illuminate.

NOTE: The Nose Gear release handle pull force will be significantly higher than experienced during practice alternate landing gear extensions.
The required pull force, to release the Nose Gear uplocks, can be as high as **41 kg** (**90 lb**).
It may require a repeated pull effort to achieve a Nose Landing Gear down and locked indication.

LANDING GEAR ALTERNATE RELEASE and
LANDING GEAR ALTERNATE EXTENSION Doors ..... LEAVE FULLY OPEN

L/G INHIBIT Switch ..... Leave at INHIBIT

CAUTION: Landing gear cannot be retracted following extension by alternate extension procedure.

CAUTION: Nosewheel steering is inoperative following extension by alternate extension procedure.

(*cont'd on the next page***)**

ALTERNATE LANDING GEAR EXTENSION or **LDG GEAR INOP (***cont'd***)**

Anti-Skid ..... Test
Hold the ANTI-SKID switch at TEST, then release to ON.
Make sure INBD ANTI SKID and OUTBD ANTI SKID caution lights go off after 3 s.

After Landing:
- Consider stopping on the runway.
  Install main gear pins and engage nose gear lock as soon as possible after engine shutdown.

[END]

Figure 13: Copy of the procedure published in the aeroplane operating manual (AOM) (Chapter 3, 3.1-56/57 [Rev. 7 of 7 March 2013]). The black vertical bars on the left margin illustrate what has been changed since the last publication of this procedure.

Annex 5: Additional procedure according to the AOM

Nose Gear - UP
Main Gear - DOWN and LOCKED

If the Alternate Gear Extension procedure has been completed and it cannot be verified that the nose landing gear is down and locked by the normal and alternate systems, the flight crew must make a decision to perform a landing with the nose landing gear not locked or reset the Alternate Extension system and cycle the landing gear in an attempt to achieve all gears down and locked.

It is possible to safely land the Dash 8 Q400 airplane with the nose landing gear retracted.

The geometry of the Q400 airplane is such that the propellers will not come in contact with the ground with the main landing gear extended and the nose landing gear retracted.

In addition to the direction given in the AFM Paragraph 3.16, Emergency Landing, the following items are offered for consideration:

- Reduce landing weight through fuel burn
- Attempt to achieve an aft CG by re-seating passengers
- Select a runway with minimal crosswind
- Land with flap 35°
- Fly the appropriate V_{REF} for the landing weight
- Touchdown offset from the runway centreline if the runway is equipped with a centreline lighting system
- On touchdown, hold the nose up off the runway as long as possible.
  Prior to losing elevator effectivity, gently lower the nose onto the runway
- If the nose landing gear is not extended or it collapses, maintain directional control with rudder until it is no longer effective, at which point asymmetric braking may be used as required
- If the nose wheel is on the ground and the nose landing gear appears to be locked, apply brakes and / or reverse thrust.
  If the nose landing gear is not extended or it collapses, apply brakes only.

Opting to cycle the landing gear in an effort to extend the nose gear from this abnormal situation would require a reset of Alternate Extension procedure.

This may be accomplished by utilizing the following procedure:

1. Ensure # 2 hydraulic system pressure and quantity are normal and the following landing gear advisory lights are illuminated:
   - selector lever amber,
   - gear green locked down (main gear only),
   - red gear unlocked (nose gear) and
   - all amber doors open.
2. NOSE L/G RELEASE handle – Return to stowed position.
3. LANDING GEAR ALTERNATE EXTENSION door – Close fully.
4. MAIN L/G RELEASE handle – Return to the stowed position.
5. LANDING GEAR ALTERNATE RELEASE door – Close fully.
6. LANDING GEAR lever – DN.
7. L/G DOWN SELECT INHIBIT SW – Normal and guarded.
   Check amber doors open advisory lights out (main gear only) and LDG GEAR INOP caution light out.

   NOTE: It may take up to 17 s for the doors to close.
8. LANDING GEAR lever – UP. Check all gears, doors and LANDING GEAR lever advisory lights out.

If the Flight Crew decides to cycle the landing gear in an effort to achieve all gears down:

9. LANDING GEAR lever – DN. Check:
   - 3 green gear locked down advisory lights illuminate,
   - all amber doors open,
   - red gear unlocked and
   - selector lever amber advisory lights out.
10. Items 8 and 9 may be repeated in an effort to achieve 3 gear down and locked.

CAUTION: **Should the LDG GEAR INOP caution light illuminate, or**
loss of # 2 hydraulic system pressure or quantity, or
any abnormality in landing gear system indication other than those associated with the nose landing gear be experienced,
see AFM Paragraph 4.21.1 (ALTERNATE LANDING GEAR EXTENSION).

Figure 14: Copy of the procedure published in the aeroplane operating manual (AOM) (Chapter 3.4.4.5 [Rev. 7 of 7 March 2013]). The black vertical bars on the left margin illustrate what has been changed since the last revision [Rev. 6 of 5 November 2012] of this procedure.

Annex 6: Procedure according to the FOSL

According to the FOSL, in the event of *„Nose Gear UP, Main Landing Gear Down",* the crew must decide whether to perform a landing with retracted nose landing gear or try to extend the landing gear correctly by cycling the landing gear (cf. chapter 1.17.3). The FOSL describes the following two procedures with notes:

„It has been demonstrated that the Dash 8 can safely land with the nose gear retracted. The geometry of the aircraft is such that the propellers will not come in contact with the runway with the main gear down and the nose gear retracted. In addition the direction given in the AFM in Paragraph 3.16, the following is offered for consideration:

- *Reduce landing weight through fuel burn.*
- *Attempt to achieve an aft C of G through passenger re-seating.*
- *Select a runway with minimal crosswind.*
- *Land with flap 35 degrees.*
- *Fly the appropriate Vref for the landing weight.*
- *Touchdown offset from the runway centerline if runway equipped with a centrelight system.*
- *On touchdown, hold the nose just off the runway with the elevator. Prior to losing elevator control, gently lower the nose to the runway.*
- *Should the nose wheel not be extended or collapse, maintain directional control with rudder until no longer effective at which point asymmetric braking can be used as required.*
- *Apply brakes or reverse thrust only after the nose-wheel is on the ground and appears to be locked. If nose gear is not extended or collapses apply brakes only.*

Opting to cycle the landing gear in an effort to extend the nose gear from this abnormal situation would require a reset of Alternate Extension procedure. This may be accomplished by utilizing the following procedure:

1. *Ensure No. 2 hydraulic system pressure and quantity are normal and the following landing gear advisory lights are illuminated: selector lever amber, gear green locked down (main gear only), red gear unlocked (nose gear) and all doors open:*
2. *NOSE L/G RELEASE handle – Return to stowed position.*
3. *LANDING GEAR ALTERNATE EXTENSION door – Close fully.*
4. *MAIN L/G RELEASE handle – Return to the stowed position.*
5. *LANDING GEAR ALTERNATE RELEASE door – Close fully.*
6. *LANDING GEAR lever – DN.*
7. *L/G DOWN SELECT INHIBIT SW – Normal and guarded. Check amber doors open advisory lights out (main gear only) and LDG GEAR INOP caution light out.*
   NOTE: It may take up to 17 seconds for the doors to close.
8. *LANDING GEAR lever – UP. Check all gear, door and LANDING GEAR lever advisory lights out.*

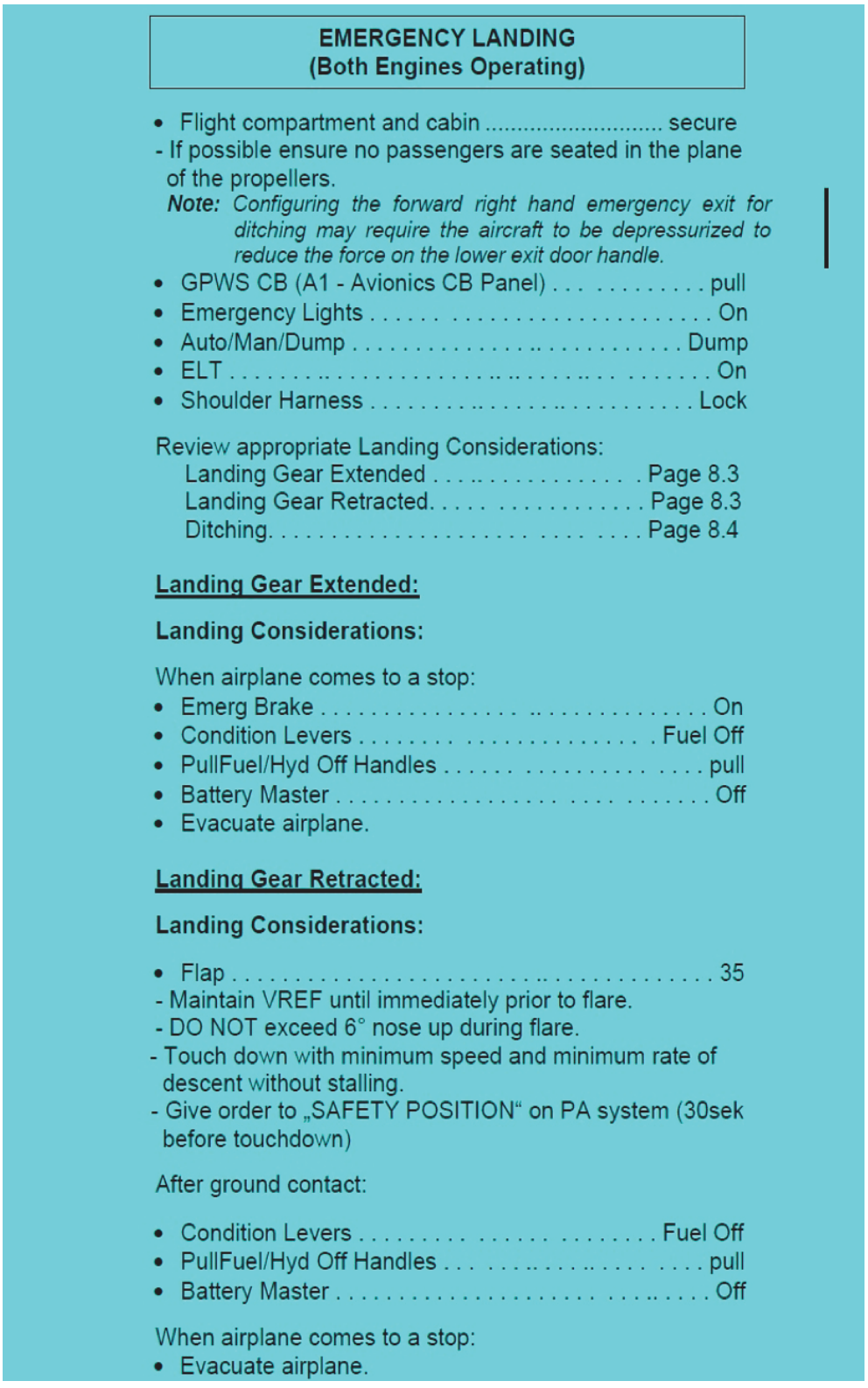
If the flight crew decides to cycle the landing gear in an effort to achieve all gear down:

9. *LANDING GEAR lever – DN. Check 3 green gear locked down advisory lights illuminate, all amber doors open, red gear unlocked and selector lever amber advisory lights out.*
10. *Items 8 and 9 may be repeated in an effort to achieve 3 gear down and locked.*

CAUTION

Should the LDG GEAR INOP caution light, or loss of NO. 2 hydraulic system pressure or quantity, or any abnormality in landing gear system indication other than those associated with the affected main landing gear be experienced, see paragraph 4.21.1 ALTERNATE LANDING GEAR EXTENSION."

Annex 7: Checklist for emergency landing according to the QRH



EMERGENCY LANDING
(Both Engines Operating)

- Flight compartment and cabin ..... secure
- If possible ensure no passengers are seated in the plane of the propellers.

Note: Configuring the forward right hand emergency exit for ditching may require the aircraft to be depressurized to reduce the force on the lower exit door handle.

- GPWS CB (A1 - Avionics CB Panel) . . . . . pull
- Emergency Lights . . . . . On
- Auto/Man/Dump . . . . . Dump
- ELT . . . . . On
- Shoulder Harness . . . . . Lock

Review appropriate Landing Considerations:
Landing Gear Extended . . . . . Page 8.3
Landing Gear Retracted. . . . . Page 8.3
Ditching. . . . . Page 8.4

Landing Gear Extended:

Landing Considerations:

When airplane comes to a stop:
- Emerg Brake . . . . . On
- Condition Levers . . . . . Fuel Off
- PullFuel/Hyd Off Handles . . . . . pull
- Battery Master . . . . . Off
- Evacuate airplane.

Landing Gear Retracted:

Landing Considerations:

- Flap 35

- Maintain VREF until immediately prior to flare.
- DO NOT exceed 6° nose up during flare.
- Touch down with minimum speed and minimum rate of descent without stalling.
- Give order to „SAFETY POSITION“ on PA system (30sek before touchdown)

After ground contact:

- Condition Levers . . . . . Fuel Off
- PullFuel/Hyd Off Handles . . . . . pull
- Battery Master . . . . . Off

When airplane comes to a stop:
- Evacuate airplane.

Figure 15: Copy of the checklist published in the quick reference handbook (QRH) (page 8.3, of 22 August 2010)

Annex 8: Nose gear alternate release detail

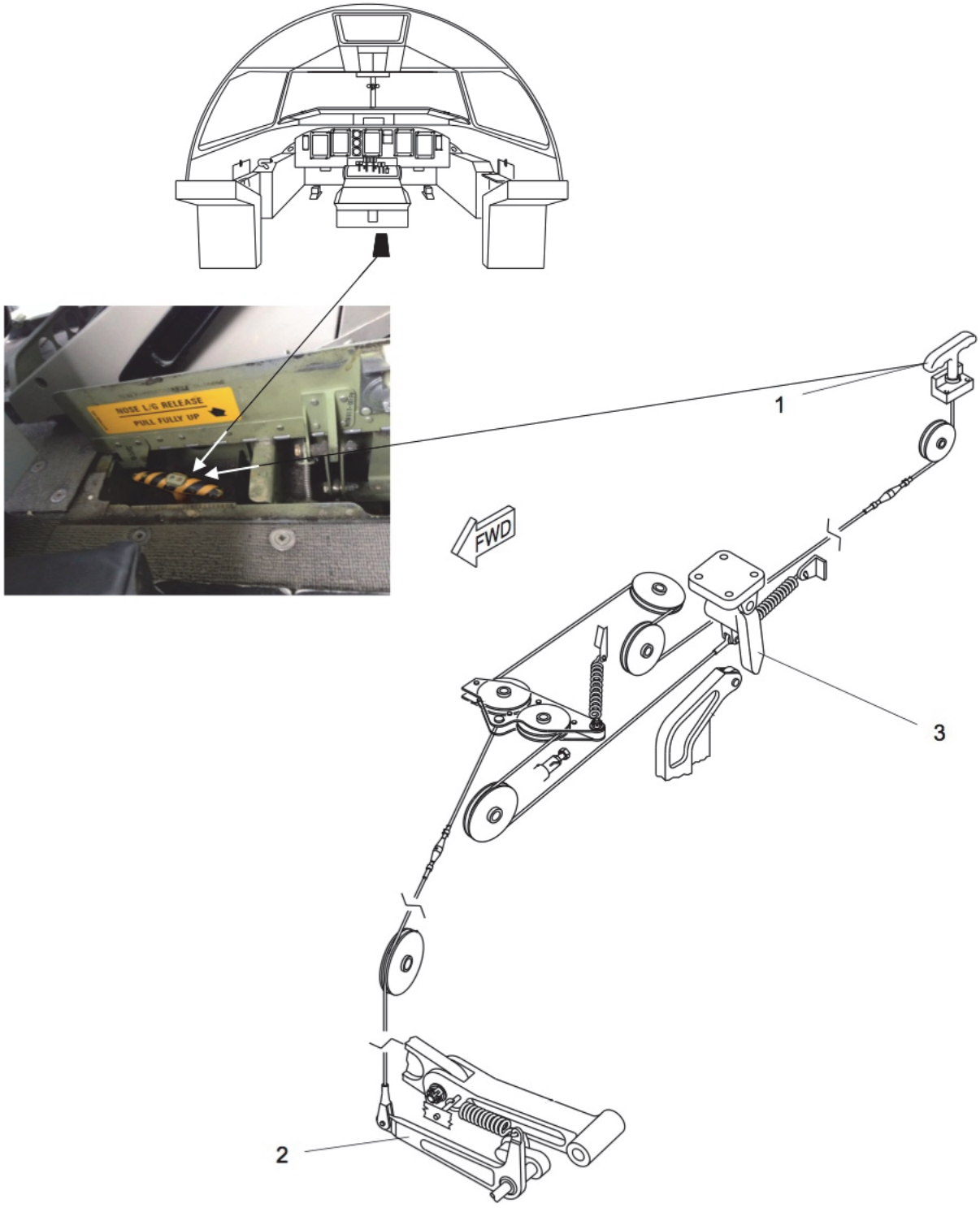


Figure 16: Schematic picture of the alternate nose gear extension mechanism (Image from the gear manufacturer, adapted by the STSB). The photo shows the opened landing gear alternate extension door in the cockpit floor.

1: NLG alternate release handle
2: front door alternate operating arm
3: NLG uplock release arm