DUTCH
SAFETY BOARD

Gear collapse during landing

Gear collapse during landing

The Hague, May 2018.

The Dutch Safety Board

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N.B. This report is published in English, a Dutch summary is available. If there is a difference in interpretation between versions, the English text prevails.

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GLOSSERY OF ABBREVIATIONS

AAIB	(UK) Air Accident Investigation Branch (United Kingdom)
AAS	Amsterdam Airport Schiphol
AD	airworthiness directive
AHRS	attitude and heading reference system
ATC	air traffic control
ATIS	automatic terminal information service
ATPL	airline transport pilot licence
CG	centre of gravity
CVR	cockpit voice recorder
DSB	Dutch Safety Board
EASA	European Aviation Safety Agency
FDR	flight data recorder
FL	flight level
FS	fuselage station, relative position on aircraft for measurement
ICAO	International Civil Aviation Organization
IFR	instrument flight rules
ILS	instrument landing system
KNMI	Dutch Meteorological Office
LH	left-hand
LILAW	loaded index at landing weight (CG)
LITOW	loaded index at take-off weight (CG)
LIZFW	loaded index at zero fuel weight (CG)
LVNL	Luchtverkeersleiding Nederland, Air Traffic Control Netherlands
MLG	main landing gear
NLG	nose landing gear
PAPI	position approach path indicator
PSEU	proximity sensor electronics unit
PSIG	pound per square inch Gauge
RA	radio altitude
RH	right-hand

SSFDR	solid state flight data recorder
SSV	solenoid sequence valve(s)
TOM	take-off mass
TOW	take-off weight
TSB (CDN)	Transportation Safety Board (Canada)
TTL	total traffic load
UTC	coordinated universal time (uniform time table, Greenwich mean time)
VMC	visual meteorological conditions
VREF	normal landing threshold speed
WOW	weight on wheels (sensor)
ZFW	zero fuel weight, dry operating weight plus total traffic load

SYNOPSIS

Collapse of right-hand main landing gear
On 23 February 2017 the aircraft registered G-JECP made a scheduled international flight from Edinburgh in the United Kingdom to Amsterdam Airport Schiphol (AAS, Schiphol) in the Netherlands. During landing at Schiphol at around 16:55 local time, almost immediately after touchdown, the right-hand main landing gear collapsed, causing the aircraft to roll to the right with the right-hand wing tip, right-hand engine nacelle and right aft body structure contacting the runway. After sliding over the runway for several hundred meters, the aircraft came to a stop. All occupants were evacuated and the crew shut down the aircraft. There were no injuries. The aircraft was substantially damaged as a result of the accident. The accident occurred in daylight under visual meteorological conditions (VMC).

Notifications after accident
The Dutch Safety Board (DSB) was notified about the accident by the Air Accident Investigation Branch of the United Kingdom (AAIB UK) at 17:20 hours, followed by a notification from the Canadian Transport Safety Board (TSB CDN), the Dutch Aviation Police (LVP) and Amsterdam Airport Schiphol Air Traffic Control (LVNL AMS). On 24 February 2017 DSB issued a formal notification to TSB CDN, AAIB UK, European Aviation Safety Agency (EASA) and the International Civil Aviation Organization (ICAO).

Relation to other accidents
There have been earlier cases where the main landing gear (MLG) of this type of aircraft (Bombardier DHC-8 of the Q400 series) has collapsed after landing, due to striking an object or as a result of a severe wheel imbalance following tire failure. These cases led to the publication of Airworthiness Directive (AD) CF-2016-31R1. During the first phase of the investigation DSB studied this AD in relation to the cause of the accident. However, no relation was found between the AD and the accident, nor was any reason found to issue a safety warning with regards to the airworthiness of the entire Q400 fleet in general in relation to the findings during the investigation.

Limitations of the investigation
During the investigation, deformation was found on the aircraft's right-hand main landing gear yoke. Analyses of the forces applied during the occurrence, and the absence of further damage to the main landing gear and the stabilizer brace assembly, indicate that this deformation was caused prior to the accident flight. Investigation of the operator's aircraft and maintenance records did not reveal any cause for the deformation of the yoke. Later analysis proved that additional damage would have been incurred to adjacent parts had the brace assembly been installed at the time the yoke was damaged. No damage to attachment points or associated parts was present suggesting that the yoke was damaged during assembly or maintenance of the main landing gear.

1 FACTUAL INFORMATION

1.1 General

Figure 1: aircraft on runway after occurrence. (source: Dutch Safety Board)

Identification number:	2017016
Classification:	Accident
Date, time[1] of occurrence:	23 February 2017, around 16:55 hours
Location of occurrence:	Amsterdam Airport Schiphol
Registration:	G-JECP
Aircraft type:	Bombardier DHC-8-Q402 (Dash 8)
Aircraft category:	Twin engine turboprop
Type of flight:	Commercial scheduled passenger flight

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

Phase of operation:	Landing
Damage to aircraft:	Substantial
Crew:	2 flight crew / 2 cabin crew
Passengers:	59
Injuries:	None
Other damage:	None
Light conditions:	Daytime visual meteorological conditions

1.2 History of the flight

The accident flight, flight BE1284, was a scheduled passenger flight from Edinburgh Airport to Amsterdam Airport Schiphol (Schiphol). The aircraft involved was a Bombardier DHC-8-Q402 twin engine turboprop passenger aircraft, with British registration G-JECP. The flight to Schiphol was the third flight in a sequence of four scheduled for the crew on 23 February 2017. The first flight of the day was from Birmingham Airport to Schiphol. The flight was scheduled to take off around 07:00 UK time, but was delayed because of the meteorological circumstances. The first landing took place at Schiphol on runway 22, with strong winds from the south-west. The flight was followed by a flight to Edinburgh Airport and a return flight back to Schiphol. The first two flights of the day were uneventful. The fourth flight was to be from Schiphol to Birmingham but was cancelled for this crew and aircraft because of the accident.

On the accident flight the aircraft departed from Edinburgh Airport without any abnormalities. The captain was acting as pilot flying, the first officer acting as pilot monitoring on this flight. During the approach to Schiphol, at approximately 16:30 hours, ATC requested the crew to hold over reporting point SUGOL at flight level (FL) 110 for 20 minutes because landing runways available were limited at Schiphol because of the strong surface wind. ATIS information “Kilo” reported winds from direction 240° with a velocity of 35 knots, gusting to 40 knots. METAR information reported winds at 37 knots gusting to 46 at 15.55 (UTC, 16.55 local time).

From SUGOL the crew initially received radar vectors inbound Schiphol. They then were cleared to intercept the Instrument Landing System (ILS) for runway 22. The ILS for the approach to runway 22 was intercepted at 18 NM. During the descend, at 16:49:17 the autopilot disengaged because of gusting winds in the approach and was reengaged by the crew shortly after.

The arrival was flown in speed control mode with an airspeed of 170 knots. Final speed was selected at 130 knots, i.e. normal landing threshold speed (VREF) plus 10 knots to compensate for the gusting winds. At around 16:51:25, approximately 5.5 NM from the runway touchdown point, the landing gear was selected down, giving three greens indication in the cockpit shortly after. The crew confirmed the indication, 15 degrees flaps were selected and de-icing systems were selected.

At 16:51:35 the crew changed radio frequency to Schiphol Tower and received a clearance for landing on runway 22. The air traffic controller reported the wind from direction 240 degrees with speeds of 36 knots gusting to 48 knots. The crew finished the before landing checklist. They then selected 5 degrees flaps and selected gear down. They confirmed 'ice protection on', 'landing gear three greens', selected 15 degrees flaps and checked 'bleed air on'.

At an altitude of 300 feet the flight crew disengaged the autopilot for landing. On short final the crew noticed the PAPI showing they were on the glide path. Although the pilots were aware they would encounter strong winds during landing, including crosswinds, the wind conditions were not extreme and were not above the aircraft's limitations. Short final was flown under crosswind conditions, with the nose of the aircraft about 20 degrees right of centre line. Just before touch down the pilot flying aligned the nose of the aircraft with the runway centreline and lowered the right wing to compensate for the crosswind, causing the right-hand main wheel to touch the runway first. The aircraft touched down at 16:51:42. The crew considered the landing to be firm, but not hard. Almost immediately after touch down the crew noticed the right wing dropping, and a red warning light appeared on the landing gear panel in the cockpit.

The right-hand propeller, right-hand engine nacelle, lower fuselage, wing tip and aileron collided with the runway and the aircraft continued for several hundred meters before coming to a complete stop. This resulted in damage to the right hand propeller, the lower fuselage structure and right-hand outboard wing tip. The right-hand fuselage was also damaged due to fragments from the right-hand propeller and stone strikes. The left-hand main landing gear and nose gear remained extended.

At 16:54:51 the crew transmitted a MAYDAY call and after coming to a complete stop the cabin attendants started evacuating the passengers via the two aft doors. The crew then shut down the aircraft in accordance with the checklist. As a precaution, they also pulled the circuit breakers from the flight data and cockpit voice recorders. During the accident and following evacuation no-one was injured.

The landing of the aircraft was filmed from several different positions. One of the passengers sitting close to the RH engine and landing gear filmed the RH MLG aft doors just prior to landing, two local TV stations recorded the landing as part of two separate television documentaries on the hard winds on the day of the accident. All video evidence indicates that the right hand MLG aft doors were open at the time of the landing.

Figure 2: moment just before landing, viewed from rear, showing aft doors open on RH MLG. (still of video)

Figure 3: moment of touchdown, frontal view. (still of video)

1.3 Aircraft damage

As a result of the accident, the aircraft was severely damaged. At the time of writing this report, it was still uncertain if the aircraft was to be repaired or be considered as a total loss.

Damage was found on the lower fuselage structure and right-hand outboard wing tip. The right-hand fuselage was also damaged due to fragments from the right-hand propeller and debris and gravel from the runway tarmac friction layer.
The nose landing gear right-hand tire was damaged during the incident. There were no visible signs of deformation to the nose gear, except for damage to the right-hand tire and outer wheel hub. The right-hand main landing gear was found to be partially within the nacelle.

The left-hand MLG was extended and supported the weight of the aircraft at an angle. There was no visible damage to the gear attachment points.

Damage observed on the fuselage consisted of partially stripped outer skin, multiple dents and a puncture caused by propeller debris and stones. At some points the skin had been scraped away on the runway resulting in a hole and shaved stringers, frames and inter costals. There was no apparent impact damage away from the perforated structure.

The right-hand (number 2) engine propellers contacted the runway surface, causing all blades to be ground down to approximately half their original length. The nacelle did not make contact with the ground, except at the outboard, aft MLG door. The engine nacelle centre and aft sections were not damaged. No damage was noted on the nacelle frames.

Figure 4: right-hand nacelle and MLG after occurrence. (source: Dutch Safety Board)

Figure 5: left-hand nacelle and MLG after occurrence. (source: Dutch Safety Board)

The MLG bay was visually inspected with the landing gear installed. Although no visual damage was initially detected, a more thorough inspection of the MLG bay (including dimensional checks) was performed after the aircraft was put in a hangar, and the landing gear was removed. During the investigation a significant misalignment was noted between the yoke and the stabilizer brace attachment points to the yoke during removal of the landing gear. Following this, all components were transported to the factory location for further inspection and isolation of the source of misalignment, where it was found that the yoke was indeed deformed.

1.4 Other damage

As a result of the aircraft scraping its surfaces over the landing runway there was damage to the top layer of the runway. The damage was such that no repairs were needed to the runway.

1.5 Salvage

After the accident the aircraft was inspected for damage in the right-hand main landing gear area. The right-hand MLG was positioned in the wheel well, the wheel well was resting on the tarmac. After it was determined that there was no obvious damage, the aircraft was salvaged using long wooden beams, air cushions and hydraulic jacks. The jacks were positioned in accordance with the maintenance manual. The aircraft was raised high enough to make the extension of the right hand main landing gear possible. There was no visible damage to the gear attachment points and no evidence of contact between the tires and the nacelle side walls. The MLG was then manually lowered and locked into position without problems, without use of hydraulic power. There were no visible abnormalities on the main landing gear or the main landing gear support after the gear was lowered. After the aircraft was standing on its three landing gears, the aircraft was slowly towed into a hangar for further inspection.

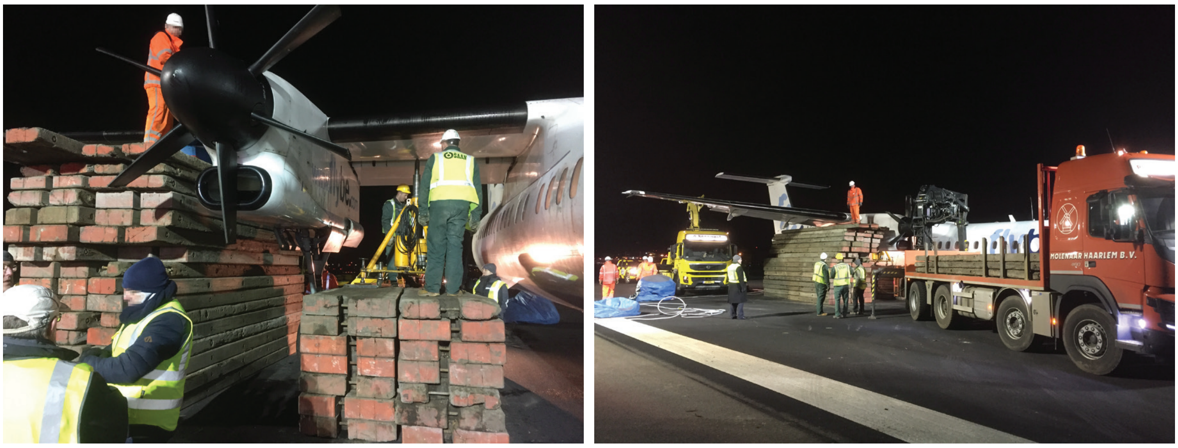

Figure 6/a: lifting the aircraft using large wooden beams and hydraulic jacks. (Source: Dutch Safety Board)

1.6 Crew

Captain
The captain was a 44 year old male holding a PPL(A), CPL(A) and ATPL(A) and type rating for the aircraft involved. His licences were valid until July 2017, his medical class 1 was valid until August 2017. The captain was pilot flying on this flight.

Flying experience (hours)	total	Last 28 days
on type	2,780	63
total all types	6,000	63

Table 1: flying experience captain. (source: operator)

First Officer
The first officer was a 28 year old male holding a PPL(A) and CPL(A) and type rating for the aircraft involved. His licences were valid until January 2018, his medical class 1 was valid until August 2017. The first officer was pilot monitoring on this flight.

Flying experience (hours)	total	Last 28 days
on type	1,090	47
total all types	1,300	47

Table 2: flying experience first officer. (source: operator)

Both cockpit crew had enjoyed an 18 hour rest period prior to their flying duties on the day of the accident.

The cabin crew consisted of two cabin attendants who both held valid licences.

1.7 Aircraft

Description of the aircraft
The aircraft is a Bombardier DHC-8-Q402 (commonly known as Dash 8). It is a high wing, twin-engine, medium-range, turboprop aircraft. Models delivered after 1997 are designated with the prefix "Q".

All recent maintenance records and maintenance actions relevant to the components involved in this accident were checked. All systems involved were inspected in detail. All records indicate that the aircraft was certified, equipped, and maintained in accordance with existing regulations and approved procedures. Although the investigation revealed that there was pre accident deformation on the yoke of the right hand MLG, there was no record of that found.

Item	type	serial number(s)	hours	date of / hours since last maintenance
aircraft	DHC-8-Q402	4136	TSN: 20,477 hrs CSN: 23,889 cycles	22/02/2017 4 Hrs, 3 Cycles
last major maintenance	C Check		15,782 Hrs / 18,574 cycles	27/11/2014 4,695 Hrs / 5,315 Cycles
landing gear RH	UTAS	MA0289	TSN: 20,477 hrs CSN: 23,889 cycles	installed since new
brace RH	UTAS	MAL-SP-0547	TSN: 15,671 hrs CSN: 17,802 cycles	22/02/2017 NDT inspection AD CF-2009-11 4 Hrs, 3 cycles

Table 3: aircraft details (source: operator)

1.8 Maintenance

There have been earlier cases where the MLG of this type of aircraft has failed after landing. On one occasion it was found that as a result of a severe wheel imbalance following a tire failure, the vibrations during these events resulted in the intermittent loss of the MLG down lock signal when one of the two proximity sensors went “far”. This in turn resulted in the de-energizing of the MLG solenoid sequence valve (SSV) and the removal of hydraulic pressure from the MLG down lock actuator. To prevent these kind of occurrences in future, an Airworthiness Directive was issued (AD Number: CF-2016-31R1) that mandates changes to the down lock sensor rigging and an increase in the lock link over-centre stop pin height. It also mandates the installation of Proximity Sensor Electronic Unit (PSEU) 30145-0601, which incorporates new software to ensure hydraulic pressure is retained in the MLG down lock actuator whenever the landing gear is down and locked and SSV becomes energized. On the accident aircraft the mandated actions in CF-2016-31R1 were performed.

On the evening before the day of the occurrence, maintenance had been performed on the aircraft at one of the company’s sub-contractor’s maintenance facilities. Here, as part of scheduled maintenance, the right hand landing gear stabiliser brace assembly was replaced. The stabilizer brace assembly comes with pre-installed proximity sensors, thus by replacing the brace, the sensors are also replaced. Brace assembly with serial number MAL-SP-0556 was replaced with MAL-SP-0547. The maintenance crew reported nothing unusual was found during and after the maintenance activities.

After the replacement of the brace assembly and sensors, a ground functional test was performed with the aircraft on jacks, whereby the gear was lowered and raised several times using the aircraft’s on board power unit. After maintenance, the aircraft had been released to service and was scheduled for flight the next day.

Figure 7: example of manual cranes used to lift the main wheels from the ground when replacing the brace assembly. (source: maintenance facility)

The operators Part-M maintenance records indicated the main gear fitting was original fit to the aircraft and has not been overhauled since delivery. There have been 5 stabilizer-braces installed to this leg during its service life. These changes have all been planned events due, either to, scheduled maintenance / modifications requirements or mandatory instruction (e.g. Airworthiness Directive). For illustration purposes, the following delineates the timeline of aircraft entry into service and associated stabilizer brace changes to event date are depicted in Figure 8.

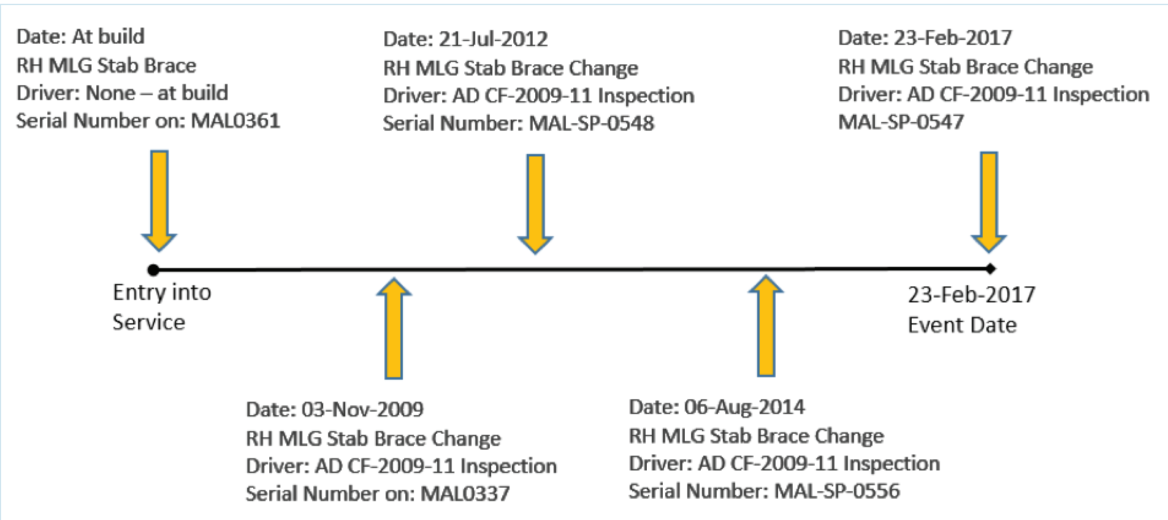

Figure 8: timeline of aircraft entry into service and associated stabilizer brace changes.

1.9 Weather

According to the Dutch Meteorological Office (KNMI) weather report, at the time of landing, a depression was moving from the United Kingdom to Germany. As a result, a strong wind field was present over the Netherlands. Visibility at the time of the occurrence was between 7 and 10 kilometres with few clouds around 2,000 feet, scattered clouds around 2,800 feet and some broken clouds around 3,700 feet. Freezing level was at 3,500 feet.

Altitude	Wind direction	Wind speed (kts)	temperature (C)
Surface	250	37, gusting 46	8
500 feet	240	50	7
1000 feet	240	55	6
1500 feet	240	60	4
FL 150			-19

Table 4: wind data. (source: KNMI)

The METAR and SIGMET at the time of landing at Amsterdam Airport Schiphol was as follows:

METAR EHAM 231555Z 24031G46KT 210V270 9999 -RA FEW020 SCT028 BKN037 08/04 Q0985 TEMPO 7000 BKN020=
SIGMETs
WSNL31 EHDB 231326
EHAA SIGMET 2 VAUD 231330/231730 EHDB-
EHAA AMSTERDAM FIR SEV TURB FCST S OF LINE N5410 E00628 - N5410 E00412 SFC/FL050 STNR NC=
WSNL31 EHDB 231516
EHAA SIGMET 3 VALID 231515/231915 EHDB-
EHAA AMSTERDAM FIR SEV ICE OBS S OF LINE N5407 E00249 - N5444 E00630 FL070/100 NC=

At the time of landing winds were strong with speeds averaging at 31 knots with gusts up to 46 knots. Although strong, the wind was mainly in the direction of landing. The calculated maximum crosswind component at the time of landing at runway 22 was 17 knots, the aircrafts' **maximum** allowable crosswind during landing on a dry runway is 32 knots.

1.10 Airfield information

The accident occurred around 16:55 on runway 22 of Amsterdam Airport Schiphol. At the time of the accident a strong south-easterly winds were present over the area gusting up to 46 knots, resulting in a 17 knots crosswind component for runway 22. Because of the weather situation, only a limited number of runways was available, with runway 24 being used as the main landing runway at the time of the accident. ATIS information K (kilo) was active, reporting runway 22 in use, 10 kilometres of visibility, and winds at 35 knots, gusting up to 40 knots.

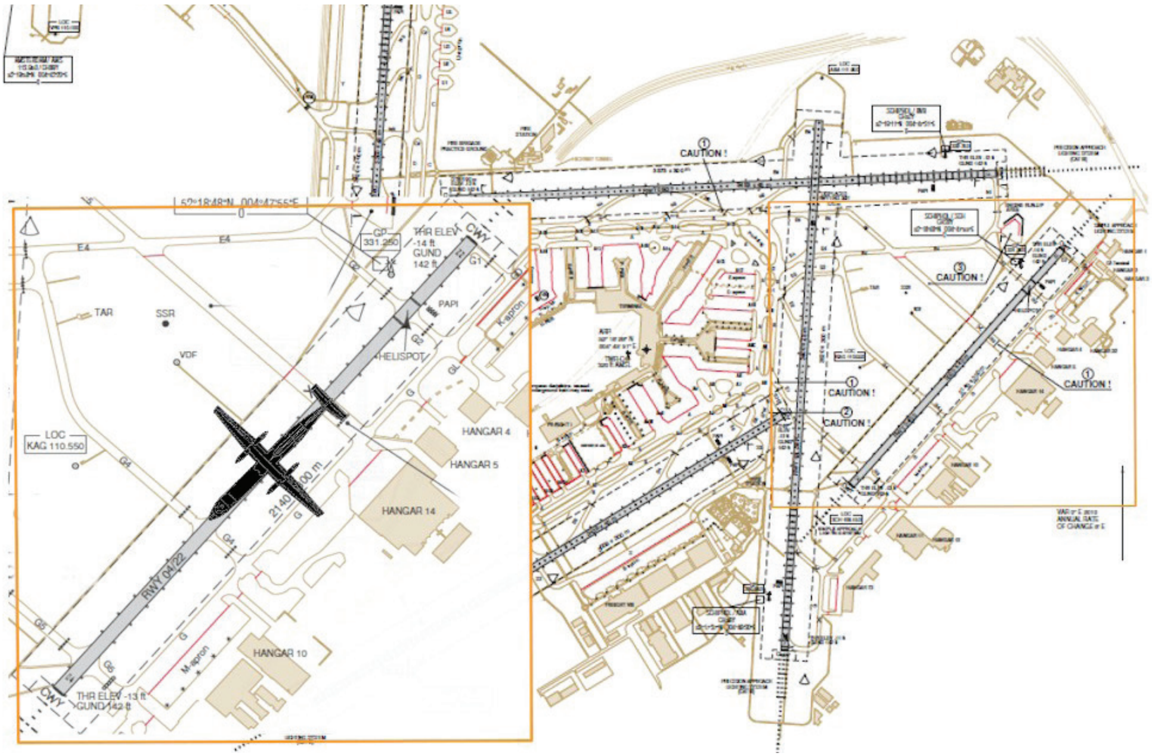

Figure 9: location of accident, runway 22 at Amsterdam Airport Schiphol. (source: AIP Netherlands)

1.11 Flight recorders

The aircraft was equipped with a solid state memory flight data recorder (SSFDR) and a solid state memory cockpit voice recorder (SSCVR). Directly after the accident, the recorders were recovered by DSB investigators and the data was downloaded with assistance of AAIB UK.

Time-history plots of the aircraft longitudinal and lateral-directional parameters are provided in Annex 3 as Figure 20 through Figure 23. In addition, these figures also present time-history plots of the linear accelerations, control surface deflections, engine related parameters, weights-on-wheels (WOW), down lock sensor information and warning/caution indicators.

According to FDR data, the autopilot was disengaged at 15:54:42 UTC[2] , at a radio altitude of approximately 420 feet, and a manual landing was performed by the crew. The FDR data show the airplane descending through 280 feet radio altitude (RA), roughly 30 seconds before the landing gear collapse.

During final approach the calibrated airspeed, roll angle, pitch angle and angle of attack were observed to show large fluctuations. In addition, average wind speed was recorded at approximately 40 knots coming from a mean direction of 243°. The flap position was set at 15 degrees. Furthermore, the propeller rotation velocity for both propellers was constant, slightly above 1000 rpm.

2 Times used in this paragraph are related to the FDR data written down in UTC

The selected source of the recorded data for longitudinal, lateral and normal accelerations, shown in Figure 21, was attitude and heading reference system (AHRS) number 1. Both AHRS systems are mounted in approximately the same location, at Fuselage Station (FS)[3] 373, near the centre of gravity (CG).

The AHRS is a system that integrates raw sensor information to determine the attitude of the aircraft. Mostly, this is done with data obtained from a set of (fibre optic) gyroscopes and accelerometers aligned with the three body axes of the aircraft. Not all aircraft are equipped with an AHRS.

A close-up of the linear accelerations and weight on wheels (WOW) sensor information at touchdown is depicted in Figure 10. Initial point of contact with the ground occurred at approximately 15:55:26.3 UTC. At this time, a vertical acceleration of 1.367 g[4] was measured. Shortly after this, at 15:55:26.8 UTC, a large magnitude peak of 1.66 g in normal (vertical) acceleration was observed. At the same time, a lateral acceleration of approximately -0.571 g[5] was recorded. Consecutively, a third larger magnitude peak of 1.387 g in normal acceleration was observed at 15:55:27.7 UTC.

Control activity, shown in Figure 21, shows that directly after the initial contact with the runway and only a fraction of a second before the second large magnitude peak in normal acceleration, a positive aileron deflection[6] of 10 degrees was recorded. Rudder activity then increases and the rudder deflection fluctuates between 7 and 16 degrees. Also, approximately 3 seconds after initial contact with the ground, the right propeller rotation velocity (NP2) falls sharply from around 1,000 rpm to 650 rpm.

Considering the WOW sensor signal and MLG and NLG down-lock sensor signals in Figure 22, it was observed that the MLG WOW sensor unit indicated AIR during the complete approach and landing. The MLG WOW sensor unit is composed of two sensors. If one of the sensors indicates AIR, the MLG WOW parameter will indicate AIR. It is not possible to derive the AIR/GROUND state of each of the sensors separately. In contrast to the MLG, the NLG WOW sensor switched to GROUND at 15:55:29 UTC, switched back to AIR until 15:55:31 UTC and finally remained at GROUND. The MLG down lock parameter indicated DOWNLOCKED up to approximately 4 seconds after initial ground contact. After that, the parameter switch to NOT DOWNLOCKED. The NLG down-lock parameter indicated DOWNLOCKED during the whole landing run. WOW sensor parameters are sampled at a frequency of 1 Hz, down-lock sensor values are sampled at 0.25 Hz.

3 Fuselage Stations designate locations along the longitudinal axis of the aircraft. The reference location of the Dash 8 series 400 is located behind the cockpit (FS-0). This aircraft extends from FS-178 to FS-1083. By default, FS are indicated in inches.

4 Note that the normal acceleration is defined as positive downward. This is due to the definition of the vertical axis, which runs from the aircraft's centre of gravity down, perpendicular to the longitudinal and lateral axes and is positive in downward direction.

5 The lateral axis, also pitch axis, runs from the aircraft's centre of gravity through the wing and is positive in the direction of the right wing.

6 A positive (right) aileron deflection causes the aircraft to roll to the left.

Two master cautions were observed; the first at 15:55:46 – 15:55:48 UTC, the second one was activated at 15:55:54 UTC. No master warnings were recorded.

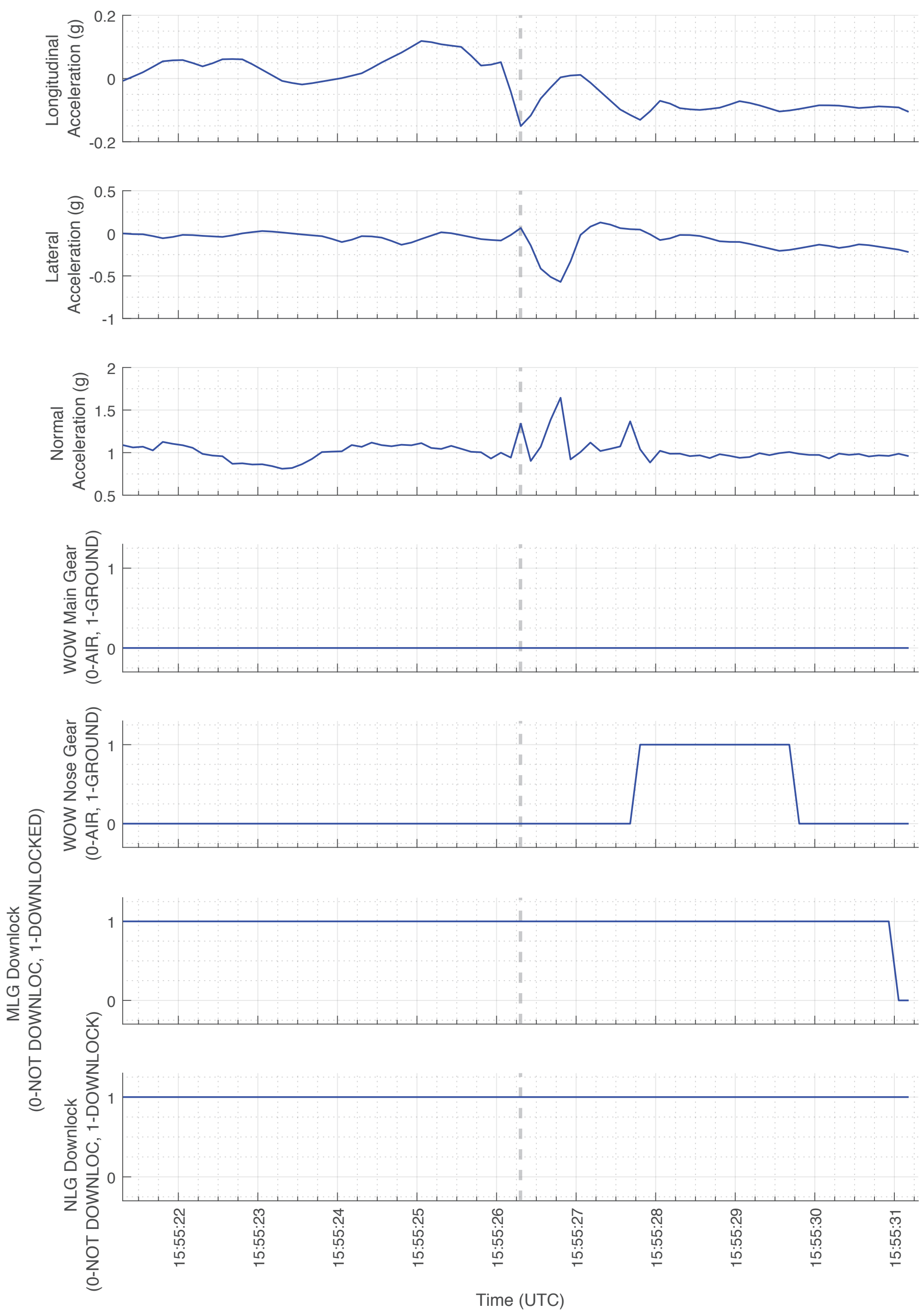

Figure 10: Time-history plot of the linear accelerations in the direction of the aircraft body axes, weight on wheels sensor information and the MLG and NLG down lock parameter. The dotted grey line indicates the point of initial contact with the ground [7].

7 WOW main gear indication in the graph shows no indication. WOW main gear is triggered when both MLG are on the ground and carry weight. It is expected (and collaborated in the video evidence) that when the right MLG contacted the ground and collapsed, the left side was not yet carrying weight. At no moment were both MLG on the ground and carrying enough load to activate the WOW sensors.

1.12 Systems involved

Landing gear system

The aircraft is equipped with a tricycle retractable landing gear. The main gears retract backwards into the nacelles located under the wing of the aircraft, holding the engines and the gear. The nose gear retracts forward into the nose section. The gear doors covering the gear open and close when the gear is extended and retracted. The doors fully cover the wheels when the landing gear is in the up position, they cover partially when the gear is extended, leaving room for the extended gear. Advisory lights are positioned in the cockpit, showing the status of the landing gear and landing gear doors. An audible warning signal warns the flight crew when the aircraft is in a landing configuration and the gear is not in the down-and-locked position.

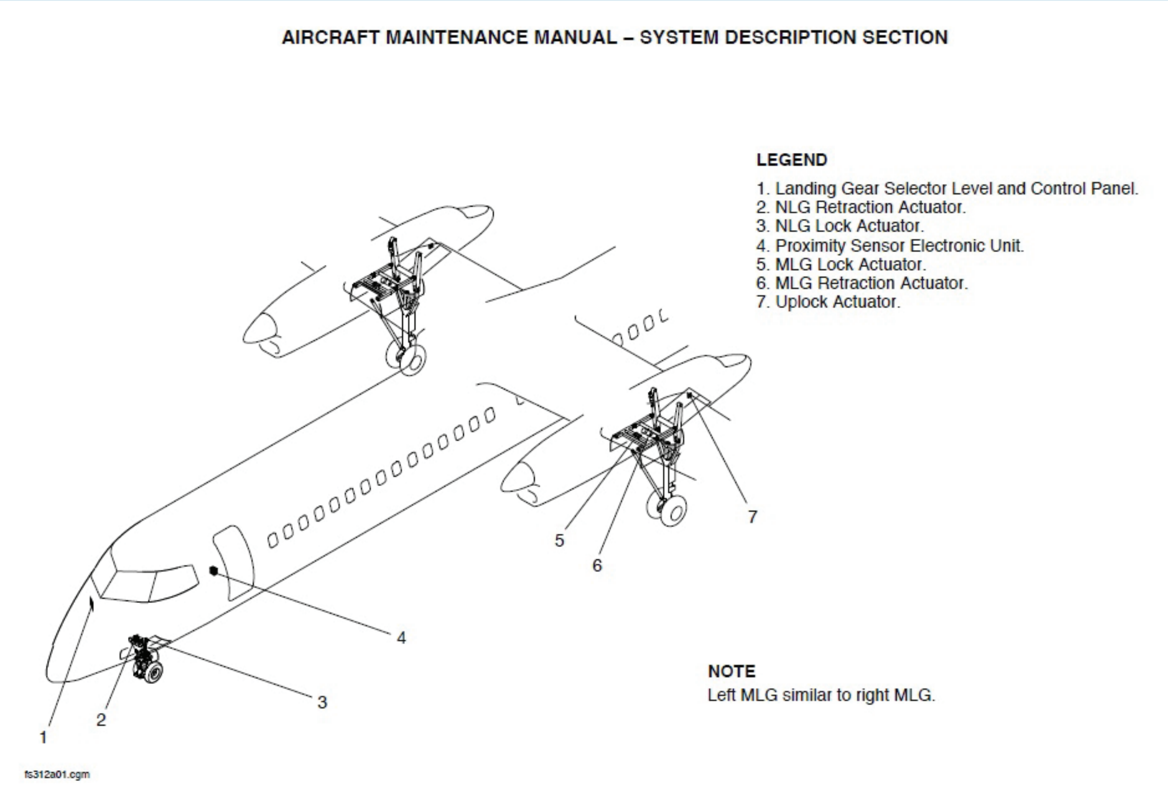

Figure 11: position of landing gear on aircraft. (source: Aircraft Maintenance Manual)

Landing gear control panel

The landing gear is controlled and monitored from the landing gear control panel. This panel is located between the two EICAS[8] displays on the forward instrument panel on the flight deck. The panel has a "landing gear selector lever" and a "lock-release selector lever". The landing gear is commanded to the up or down position with the "landing gear selector lever". The control panel also contains landing gear and landing gear door advisory lights, and a landing gear warning horn/mute test switch. An amber light in the "landing gear selector lever" is illuminated when the landing gear position does not correspond to the "landing gear selector lever" position.

8 Engine indicating and crew alerting system

Figure 12: landing gear control panel in flight deck position. (source: DSB)

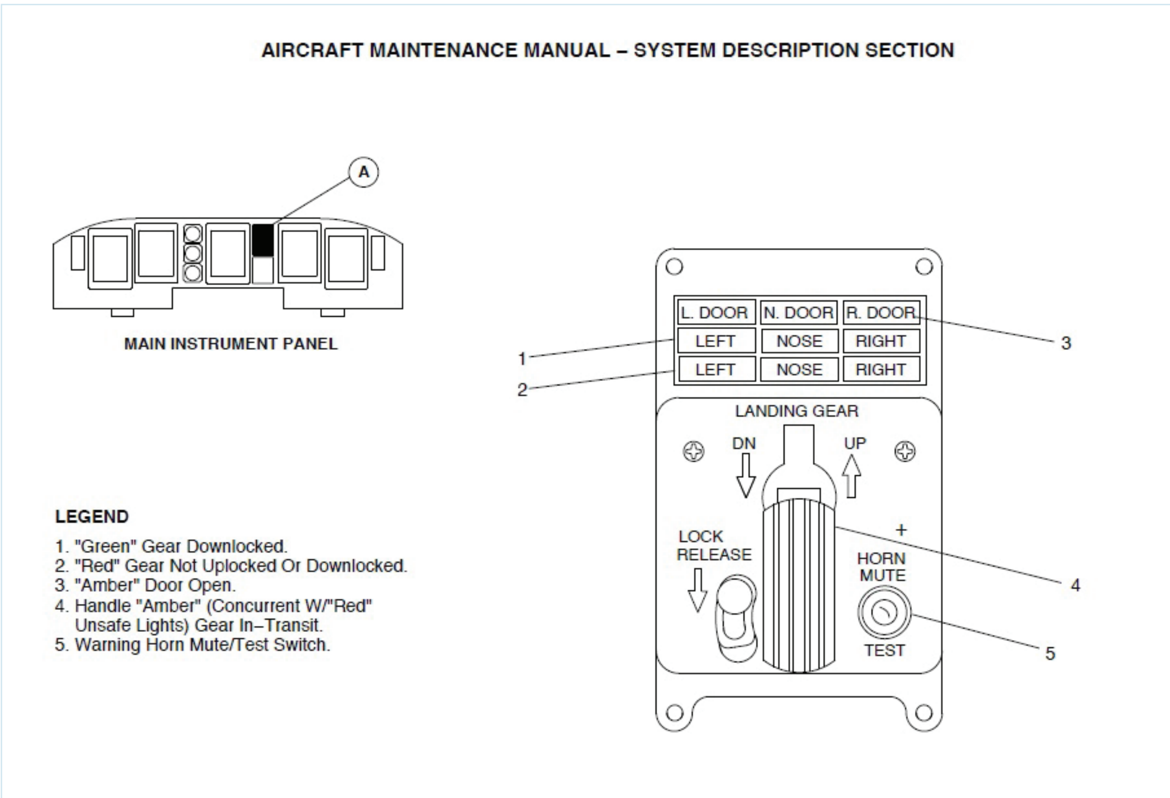

Figure 13: landing gear selector lever and control panel. (source: Aircraft Maintenance Manual)

Stabilizer brace

The stabilizer brace is a 2-piece folding structural component (figure 14). The stabilizer brace keeps the yoke and the shock strut in position when the MLG is in the extended or retracted position. The forward section of the stabilizer brace is attached to the airframe structure in the forward section of the nacelle / landing gear bay with 2 hinge points. The aft section of the stabilizer brace is attached to the yoke of the MLG, also with 2 hinge points.

Attached between the 2 sections of the stabilizer brace is an over-centre link sub-assembly that comprised of forward and aft lock links. The mechanical lock is released by the unlock actuator. The forward and aft stabilizer braces are moved into a mechanical lock position by the down lock springs during the MLG extension sequence. Two lock springs keep the links in the mechanical lock position when the MLG is extended. If there are no anomalies present on the gear, unlock actuator extend pressurization is not required to keep the gear down in lock for original certification load cases.

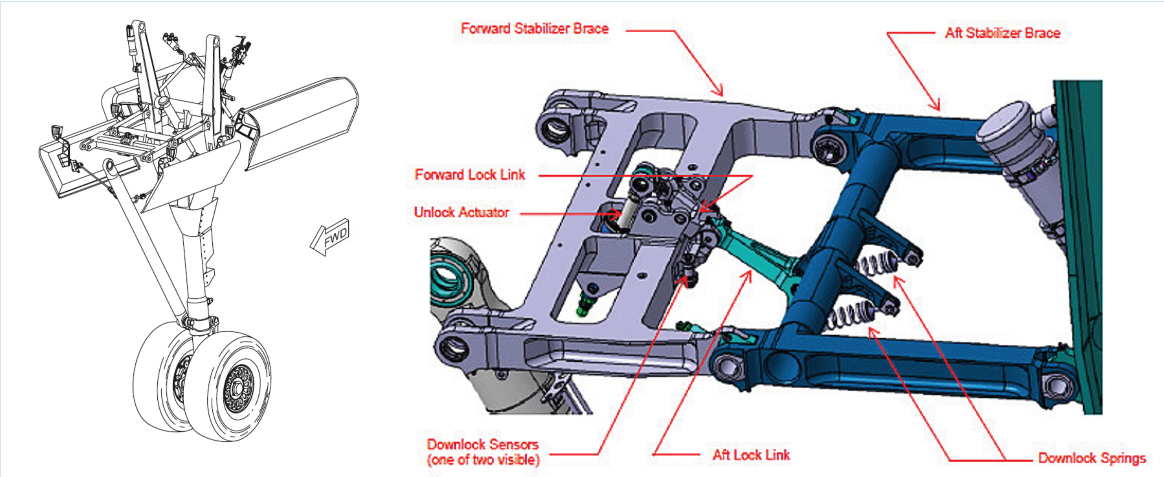

Figure 14: landing gear and stabilizer brace, locked position, retraction actuator coloured yellow. (source: landing gear manufacturer)

Gear sensors and target plates

Two proximity gear sensors, so called down lock sensors, are located on the brace. The sensors measure inductance relative to their distance from so called target plates. When the gear is selected down, the PSEU verifies the “down and locked” position through signals sent by the 2 sensors, positioned on both main gear. Two other sensors are present on each side for measuring up lock and gear door position.

When the gear sensors and target plates are nearby each other, they will generate sufficient inductance. This is interpreted by the PSEU as “gear down and in a locked condition”. This is referred to as indicating “near”. When this inductance is outside the pre-set range, the PSEU considers the gear to not be “down and locked position, and the proximity sensors are interpreted by the PSEU as being “far”. The PSEU controls a number of valves that trigger hydraulic sequences to extend or retract the landing gear.

The position of the landing gear (up, travelling or down) and the position of the landing gear doors when open is shown in the cockpit by means of indicator lights (amber lights for the gear door position, red light – gear unsafe -, no light – gear in uplock, or green light – gear in down lock – for the gear position) on the landing gear control panel.

Figure 15: stabilizer brace assembly (left) with gear proximity sensors and target plate (right).

Proximity Sensor Electronic Unit

The landing gear is controlled by selection of the landing gear selector lever and the proximity sensor electronic unit (PSEU). The landing gear is powered from the number 2 hydraulic system. Hydraulic retraction or extension starts when the landing gear selector lever is moved to the up or down position. The PSEU then checks the indicated position of the landing gear doors, and verifies if the position is in agreement with the landing gear selector position.

The PSEU uses different logic equations to drive the MLG safe indication and MLG door sequence valve during gear extension. For getting a MLG safe indication, one of the following two conditions need to be met:

- If both down lock sensors on either MLG are **not** flagged as faulted, then **both** these sensors should read “TRUE”;
- If one of two down lock sensors is flagged as faulted, then the other, healthy (non-faulted), sensor should read “TRUE”. For the MLG door sequence valve signal to be activated (which pressurises the unlock actuator and closes the MLG aft doors after gear extension), **both** down lock sensors should read “TRUE”; however, if a down lock sensor is flagged as faulted by the PSEU prior to extension, then the default state of that sensor is always “FALSE”, which prevents RH MLG door sequence valve signal activation.

Main landing gear unlock actuator

The MLG unlock actuator has 2 ports, to which hydraulic lines are attached. The MLG unlock actuator is attached to the MLG stabilizer brace assembly. The unlock actuator’s primary function is to unlock the stabilizer brace as a prelude to gear retraction as well as to supplement the over centre lock with hydraulic pressure and provides additional over centre force. When the MLG is down and locked, pressurization of the unlock actuator extend side augments the force from the down lock springs, helping the lock links to stay in an over-centre position. The mechanical analysis of this installation provides no additional force to aid in providing a down lock unless lock link stop is not in contact with the stop-pad. This condition would preclude hydraulic activation of the unlock actuator because the down lock sensors would prohibit that function.

Landing gear selector valve
The landing gear selector valve is a self-contained assembly with 2 solenoid valves. The landing gear selector valve controls hydraulic pressure to position a directional control valve that is spring-centred. The position of the valve controls the supply of hydraulic pressure to either the up or down hydraulic circuits of the landing gear system.

Main landing gear extension
The landing gear is operated by the gear selector lever in the cockpit. When the lever is moved to the down position, the solenoid sequence valves (SSVs) supply hydraulic pressure to the retract side of the MLG aft doors actuators, opening the MLG aft doors. When the MLG aft doors are approximately 93% open, the MLG aft doors linkage operates the mechanical sequence valve. The valve then supplies hydraulic pressure to the up-lock release actuators and to the down side of the MLG retraction actuators. The MLG then travels to the down and locked position.

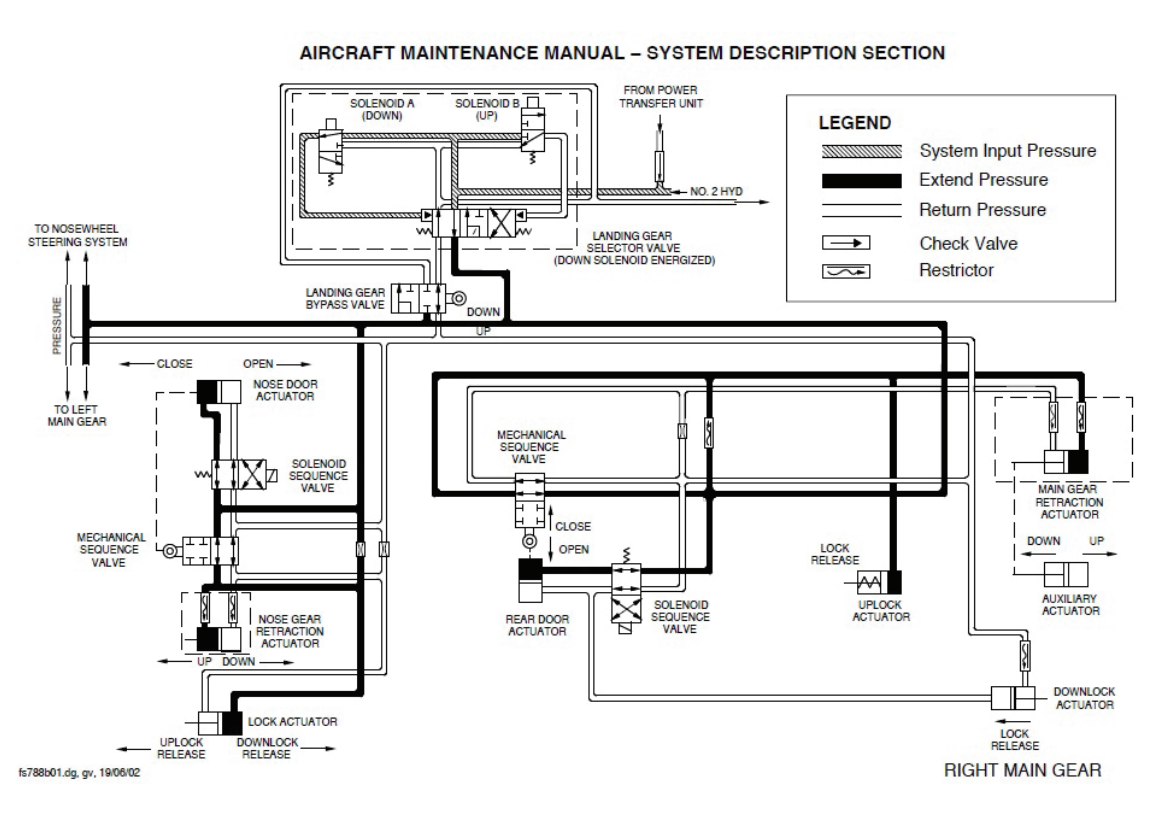

Figure 16: hydraulic scheme, extending landing gear down (source: Aircraft Maintenance Manual)

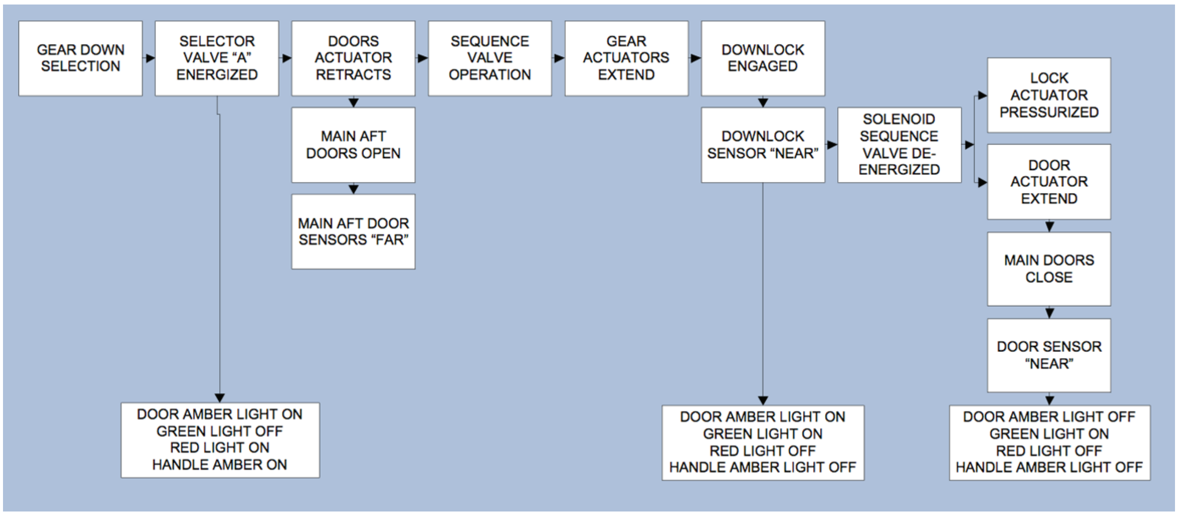

Figure 17: sequence of events gear down selection.

Three proximity sensors on each gear monitor the MLG extension sequence. Each MLG has 2 sensors that monitor the down-and-locked position, and 1 that monitors the aft-doors-closed position. When the PSEU receives input signals from both down lock sensors that the MLG is down and locked, the PSEU energizes the SSVs. Pressure is then supplied to the MLG aft doors actuators to close the aft doors of the MLG.

At approximately 7% reverse travel of the MLG doors, the mechanical sequence valves close. This action isolates the MLG retraction actuators from the rest of the hydraulic system. In-line restrictors or full pressure upstream of the mechanical sequence valve keep the down side of MLG retraction actuators pressurized to 3,000 pounds per square inch (psi) at the end of the extension sequence. When the landing gear is down and locked, the SSVs and the down solenoid of the selector valve are kept in an energized condition. This condition maintains hydraulic pressure on the down side of the retraction actuators and the down side of the MLG unlock actuators. Unlock actuator extend side pressure augments the force from the down lock springs.

2 INVESTIGATION AND ANALYSES

2.1 Flight to Schiphol

The flight was prepared and conducted in accordance with the company regulations. During the accident flight, as well as the two previous flights, no abnormalities were discovered by the crew. The crew were prepared for the landing in a crosswind condition and stated they had green light indications for the MLG, indicating it was down and locked. According to the crew, they did not notice any cockpit indication of malfunctioning of the MLG or the MLG aft doors (amber lights). Persistent illumination of the amber lights after gear extension does not require any immediate action from the flight crew, it does however require that maintenance is due after landing if they remain illuminated as a result of faulty operation of the system.

The approach and final leg were flown according to the procedures and without abnormalities.

Although there was a strong wind, the aircraft crosswind limitations were not exceeded. The landing was firm but the collapse of the right hand main gear came as surprise for the flight crew. When the aircraft came to a rest after sliding over the runway, the crew took all measures according to the checklist to shut down the engines and aircraft systems. Evacuation was started by the cabin attendants as soon as the aircraft came to a standstill. Nobody was injured, the aircraft was seriously damaged.

The weather at Schiphol was VMC with strong winds from the right at landing. The wind speed resulted in a restricted runway use.

Although there was a strong wind field over Schiphol at the time of the landing, the weather conditions were well within the aircraft limitations. The airfield was fully serviceable with runway 22 as main landing runway for small and medium size aircraft in use but with limited available runways.

After the landing gear was selected down, the green down lock MLG indications were illuminated. The crew did not notice the amber door-open-caution lights.

2.2 Flight Crew

The flight crew was certified and qualified to fly the aircraft. Their medical certificates were valid, and the crew had rested sufficiently prior to the first flight of the day. The crew performed in accordance with the general and company regulations and standards.

2.3 Aircraft

At the time of the accident the aircraft was released to service and all required maintenance was performed. There were no maintenance deferred items on the aircraft. The damage found on the aircraft as described before was all caused post-impact by the aircraft sliding over the runway after the right hand MLG collapsed after landing with exception of the right hand MLG yoke deformation. Factory analyses of the MLG yoke and brace assembly indicated that the deformation of the yoke was not a result of the accident, and therefore was present prior to the approach to the accident.

At the time of the accident, there were no recorded maintenance deferred items on the aircraft.

2.4 Mass and balance (extract from Load Sheet Final)

According to the calculations made by the crew prior to take off, the aircraft mass was 26,104 kilograms at departure, with a planned landing mass of 24,862 kilograms. Both take-off and landing masses were within the aircrafts limits (respectively 28,998 and 28,009 kg).

Item	actual (kg)	max allowable (kg)
load in compartments	447	
passengers' luggage	4,707	
total traffic load	5,154	
dry operating weight	18,120	
zero fuel weight actual	23,274	25,855
take-off fuel	2,830	
take-off weight	26,104	28,998
trip fuel	1,242	
landing weight	24,862	28,009

Table 5: masses. (source: company)

The aircraft's balance was calculated prior to take off. The calculated indexes were 397.97 for take-off (loaded index at take-off weight) and 397.28 for landing (loaded index at landing weight). Both indexes were within the aircraft limits.

Item	calculated	min allowable	max allowable
Basic index (BI)	391.04		
Dry operating index (DOI)	381.52		
Loaded index at zero fuel weight (LIZFW)	396.45	378.78	411.83
Loaded index at take-off weight (LITOW)	397.97	371.40	414.49
Loaded index at landing weight (LILAW)	397.28		
MACZFW	25.77		
MACTOW	26.56		
MACLAW	26.23		

Table 6: balances. (source: company)

2.5 Maintenance

General

Aircraft Maintenance Log (AML)
Examination of the AML does not show any landing gear problems in the period from February 10th until February 22nd. On this last date, technical orders Q400/32/12965 and Q400/29/12343 were performed. Scheduled replacement of the RH MLG stabilizer brace assembly (Airworthiness Directive) and replacement of the LH and RH MLG upper Hydraulic flex hoses were performed the day prior to the mishap flight. The stabilizer brace assembly comes with pre-installed proximity sensors, thus by replacing the brace, the sensors are also replaced.

According to the maintenance crew nothing unusual was noticed during maintenance activities. Maintenance crew stated that positioning of the brace assembly went smoothly and did not require force to position all four of the pins holding the brace in place. It is unclear if the gear, when in a bend position to be able to take the pins out and reinstall them, was moved slightly to make removal and installation of the pins easier. When replacing the brace assembly, there was no need to check if the MLG yoke showed indications of bending, twisting or misalignment.

After the replacement of the brace assembly and sensors, a ground functional test was performed with the aircraft on jacks, whereby the gear was lowered and raised several times using the aircraft's on-board power unit. The gear operated normally, the brace assembly came in the over-centre position, proximity sensor indications were normal, and the solenoid sequence valves were activated, closing the MLG aft doors and extending the MLG unlock actuator.

On the evening before the accident flight the RH brace assembly was replaced, together with pre-installed proximity sensors.

2.6 Landing gear system

PSEU and sensors

Video evidence shows that both right hand MLG aft doors were open during landing. Normally all MLG aft doors are closed as a result of the sequencing of the PSEU. With the right hand doors open, an amber door advisory light should show in the cockpit. Because the indication of the amber lights are not part of the information stored on the FDR, it cannot be said with certainty if and when the RH amber light illuminated, and for how long, but normally with the door open the light should be on. The crew stated they did not notice an amber caution light. The fact they did not notice the light was probably the result of the crew being focussed on the landing and looking outside after they had confirmed that they had three greens for the landing gear. Should they have noticed the amber light, no further action was required from the flying crew, other than inform maintenance of the issue, since normally open gear doors do not directly affect landing the aircraft.

The aft right MLG rear doors were in the open position during landing. This indicated that the SSV had commanded them to open, and not close them after the landing gear was fully down. The PSEU logic means that the open doors are a result of one of the two proximity sensors being faulted. For the MLG door sequence valve signal to be activated, both down lock sensors should read "TRUE". In this case, one of the sensor was faulty and prevented the RH MLG door sequence valve signal activation. At the same time however, when the doors are not closed, activation of the unlock actuator is also prevented since this is operated from the same hydraulic line.

After the salvage of the aircraft, when the aircraft was placed on jacks in a hangar for inspection and possible repairs, the MLG and all systems involved were inspected and checked for operation. No components of the MLG showed any visible damage other than post impact damage. During investigative testing in the hangar, the landing gear was retracted and extended several times, both with use of the aircraft auxiliary hydraulic pump and by free fall. Both the main landing gear systems performed correctly, but the right-hand MLG failed to go into locked (down) position without the use of the alternate extension actuator.

The PSEU memory was checked for fault codes. Several faults codes were found in the memory of the PSEU leading to signals from the proximity sensors during the approach. Fault codes are stored in the PSEU memory and are not presented to the flying crew. The PSEU fault code history is depicted in Table 8 of Annex 1. Fault codes indicated "normal" faults that were the result of maintenance on the evening prior to the accident flight (FLT 03 in annex), followed by fault codes originating from the accident flight and the two flight before on the same day (FLT 00, 01 and 02 in annex).
Some of the fault codes originate from the accident and post accident recovery. Fault code RGDNLK2 (Proximity Sensor Short) indicates one of the sensors was shorted for some time during the approach, resulting in the failure of the RH MLG aft doors to close after RH MLG extension, and thus also not activating the unlock actuator. This is shown in the cockpit by means of one or more amber lights illuminating in the landing gear control panel and requires no action from the pilots during landing.

In the hangar at Schiphol, the proximity sensors were inspected for readings with different gaps between the sensors and the sensor plate. Both sensors showed normal indications under room temperature conditions. However, when the sensors were frozen with aid of nitrogen spay, one of the sensors' readings became out of specifications, going below the "far" limit, thereby getting flagged as faulted by the PSEU.

PSEU BITE queried for sensor inductance	
LGDLK1 (left gear down lock 1)	8.504 to 8.520 mH
LGDLK2	8.428 to 8.438 mH
RGDLK1 (right gear down lock 1)	8.420 to 8.436 mH
RGDLK2	8.205 to 8.232 mH
NGDN1 (nose gear down 1)	8.326 to 8.348 mH
NGDN2	8.365 to 8.395 mH
NGLK1 (nose gear lock 1)	8.223 to 8.238 mH
NGLK2	8.348 to 8.360 mH

Table 7: PSEU BITE results.

During the investigation the proximity sensors were removed from the brace and were tested separately. X-ray photography showed that one of the sensors' wire spools showed a irregularity in the wire. When tested under room temperatures, the sensors did not show any malfunction or erratic readings. The sensors were then exposed to sub-zero temperatures and slowly warmed up to room temperature, comparative to the situation the aircraft was in coming down from altitude during the approach, when temperatures changed from -19° C to +8° C.

Figure 18: proximity sensor, and x-ray of sensor showing irregularity in loom.

During testing, one of the sensors showed indications out of the normal spectrum. This is in line with the PSEU fault readings initiated during the approach. The fault most likely caused the doors to remain open and the down lock actuator not activated after the MLG was fully down during the approach. This is in line with the PSEU logic described earlier.

On the evening before the accident flight the RH brace assembly was replaced, together with pre-installed proximity sensors.

Main landing gear assembly

As part of the initial investigation, the landing gear stabilizer brace and the MLG leg were visually inspected and tested. When the investigative team tried to remove and re-install the brace assembly with the gear at a midpoint between retracted and extended position without sideward forces applied to it, both removal and re-installation of the pins holding the assembly required force. The MLG had to be moved left (looking forward along the aircraft) several inches (in a bend position, approximately 45 degrees between the up and down position) in order to reposition the pins. When doing so, the pins could be positioned with relative ease. This is important to note, because when installing the new brace during maintenance, with use of hydraulic jack and the gear being in a bent position also, might result in the pins being positioned without real force, despite the fact the yoke was already deformed prior to the accident.

The fact that the pins could not easily be removed or repositioned during the investigation was a first indication of a possible bending or twisting of the MLG strut or brace assembly. When trying to replace the RH brace assembly with the left one, the same misalignment occurred, indicating the cause of the misalignment was in the MLG strut itself, and not within the brace assembly.

MLG static and dynamic analyses
The gear was examined and tested in-situ at Schiphol after the event, in a manner that minimized any destruction of evidence from the event. It was apparent early on in this phase of the investigation that something was amiss with the geometry of the gear as evidenced by the inability to down lock in a manner that was expected during the (unpowered) hangar testing. It was discovered that the yoke was deformed when the stabilizer brace was detached from the yoke. Analysis of the loads from the landing rollout, proved that the "twist" in the yoke would not have incurred after the gear collapse. The stabilizer brace was re-installed to the deformed yoke by the on-site team.

UTAS models and analysis determined that dynamic vibration was not a likely cause of the gear collapse. Frame by frame analysis of the video from the landing showed that the gear unlocked in less 135 milliseconds from initial contact with runway. After many scenarios were conceived and analysed, modelling showed that damage to the yoke / stabiliser brace attachment fittings, as well as the aft brace segment, would have been incurred had the stabiliser brace been installed at the time sufficient load was applied to the yoke to cause the deformation. This led to a conclusion where the yoke deformation was incurred at a point in time where the stabiliser brace was not installed.

After the accident the right-hand landing gear and brace were removed from the aircraft and sent to the factory. There, both the brace and MLG strut were further tested and compared with design specifications. The inspection revealed no anomalies in the brace; however, a suspected deformation was found in the yoke of the right-hand MLG leg. The MLG was then subjected to a series of tests and analyses. The analysis broadly encompassed the following:

- dynamic analysis of the MLG using dynamic analysis software (ADAMS),
- structural (static) analysis of the MLG using FEA (Finite Element Analysis) software.

The objective of the dynamic analysis was to determine if a MLG that is in a certification state (i.e. is configured and is operated in the realm of expected conditions) would experience unlocking of the stabilizer brace assembly, and consequent collapse of the MLG, for the landing experienced at Schiphol.

The dynamic analysis indicated that, for the landing conditions experienced by the mishap aircraft and for a MLG that is in a certification state:

- The stabilizer brace does not unlock (i.e. the MLG does not collapse) at any time during the simulation, therefore meets the design specifications,
- Both stabilizer brace apex joints maintain their over centre position at all times, therefore meets the design intent,
- The lock link does not lift off the stop pad, thus meets the design intent.

The results of the analyses led to questioning whether the RH MLG was indeed in a certification state just prior to touchdown at Schiphol. During post-accident inspections, the yoke from the RH MLG was found to have suffered permanent deformation. If this permanent deformation existed prior to the touchdown at Schiphol, it could have potentially affected the geometry of the stabilizer brace assembly, resulting in conditions outside the certification state. Therefore, structural (static) analysis was conducted by the landing gear manufacturer to determine the conditions under which the yoke could suffer permanent deformation, as observed during post-incident inspections (with respect to both shape and amount).

On the evening before the accident flight the RH brace assembly was replaced, together with pre-installed proximity sensors.

Structural (static) analysis
The structural (static) analysis encompassed the following:

- Elasto-plastic analysis of the yoke and cylinder,
- Static instability analysis of the stabilizer brace assembly.

The elasto-plastic analyses indicated that:

- It is unlikely that the observed amount of permanent deformation on the yoke was caused by landing or ground-manoeuvring loads,
- It is likely that the gear was positioned in Configuration 2 (see annex 3) and loaded laterally to create the observed permanent deformation on the yoke. In the cases considered, only the yoke suffered permanent deformation within the MLG leg; the deformation of the cylinder was elastic.

Static Instability Analysis of Stabilizer Brace Assembly
The objective of the static instability analysis was to determine whether a stabilizer brace assembly unlocks under torsion loading of the MLG, if one or both stabilizer brace assembly apex joints (which are designed to be in the over centre position when a gear in a certification state is down) are under centre. If the yoke was deformed prior to touchdown at Amsterdam, then it could potentially prevent both the stabilizer brace apex joints from reaching the over centre position. Torsion loading of the MLG was selected because the landing at Amsterdam resulted in a time-delay between touchdown of the RH tire and LH tire on the RH MLG (caused because of the right-wing-down roll angle at touchdown), which results in a torsion load applied to the MLG. A representative landing case that produces torsion loading was selected from the certification loads deck. The stabilizer brace assembly was modelled with fully-deformable 3D components that could capture static instability behaviour of the assembly.

Structural static analyses
After the results of the First tests were presented, further testing was done to look at the possibilities of the yoke being deformed in relation to the deformation of the stabilizer brace assembly. For this purpose the plastic properties for Al7075-T73 were applied to both stabilizer braces (same material properties as yoke). The goal is to see whether the stabilizer brace or nacelle attachment points suffer any noticeable permanent deformation if the yoke is deformed to the extent it was observed from the earlier measurements.

Two cases were analyzed to envelope the results with a rigid nacelle:

- 10.5” negative lateral displacement on the axle,
- 11.5” negative lateral displacement on the axle.

The results were compared against the rigid nacelle (RH MLG) case with 10.5” positive lateral displacement applied to the axle.

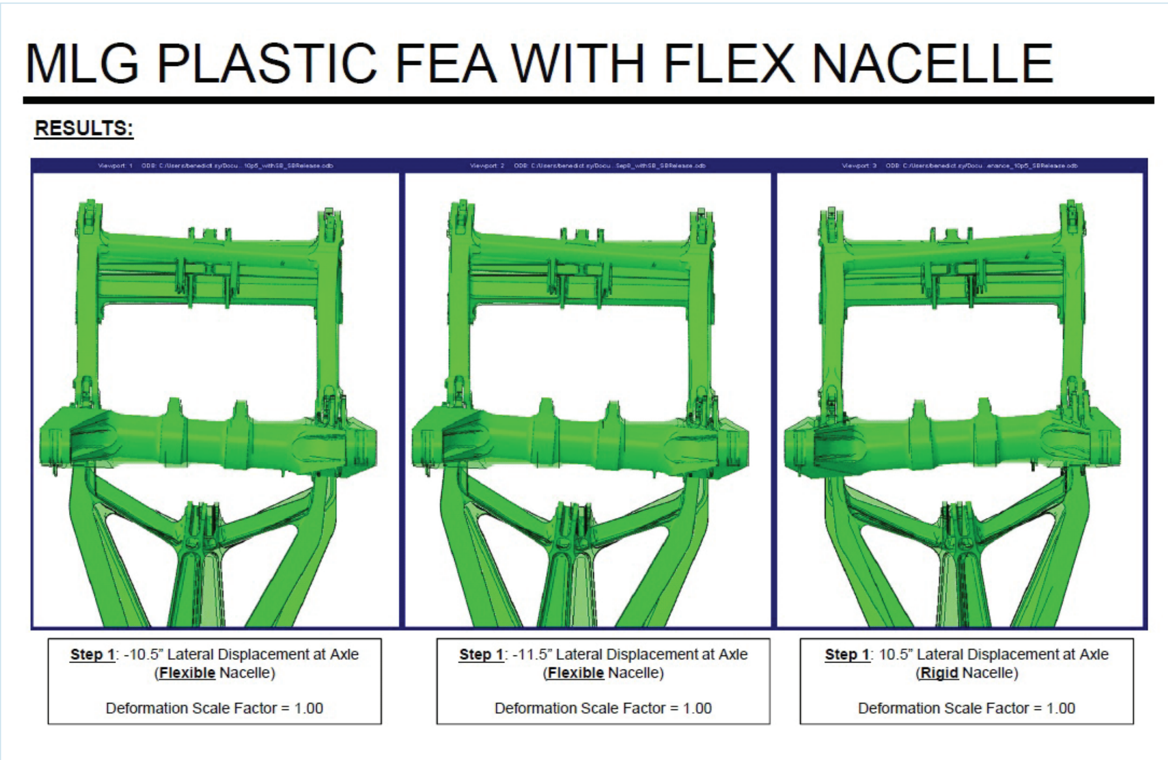

Figure 19: results of plastic deformation analyses. (source: landing gear manufacturer)

Results of Static Instability Analysis
The static instability analysis indicated that if one or both stabilizer brace assembly apex joints (which are designed to be in the over centre position when a gear in a certification state is down) are under centre, potentially as a result of a deformed yoke, then the stabilizer brace assembly would unlock under loads from a representative landing case (under limit loads).

Further testing predicted that if a stabilizer brace assembly was installed at the time the yoke was deformed to the extend it was observed, the aft stabilizer brace should also have suffered permanent deformation. From the graph shown above, the aft stabilizer brace would have experienced permanent plastic strain even at relatively low lateral displacements. No permanent deformation was found in the aft stabilizer brace of the accident aircraft. If the aft stabilizer brace would have been deformed, it could not have been installed properly in the fixture as shown above. From the statements from the maintenance crew, there was no issue installing the brace assembly in the fixture. It is therefore highly unlikely that the aft stabilizer brace assembly from the accident was installed when the deformation of the yoke occurred.

Analyses predicts that if a stabilizer brace assembly was installed at the time the yoke was deformed to the extent it was observed, the yoke attachment lugs for the aft stabilizer brace should also have suffered permanent deformation. No deformation was found on the lugs for the aft brace on the accident yoke. It is therefore highly unlikely that ANY stabilizer brace assembly was installed when the deformation of the yoke occurred. This leads to the conclusion that the deformation of the yoke took place when the aircraft was not in a flying condition.

Based on the analysis conducted by the landing gear manufacturer, and the fact there was no deformation or damage found on the stabilizer or yoke attachment lugs, the deformation on the yoke most likely was present prior to touchdown at Schiphol. This deformation was caused when NO stabilizer brace assembly was installed.

This situation only exist when the aircraft is under construction or maintenance. It is not determined when the deformation of the yoke occurred, this could have happened at any time between production and the time of last maintenance on the aircraft.

2.7 Actions taken

In the period following the event until the release of this report, the following actions were undertaken.

Aircraft Manufacturer:

- Investigate the possibility to incorporate into the AMM:
  - Possible change in task for the stab brace change to identify a possible yoke distortion,
  - Possibility to incorporate common checks for the stab brace change to verify down lock sensor serviceability in both the near and far configuration,
  - Incorporate a caution “with the stabilizer brace removed, do not induce any side loads to the MLG shock strut while in the retracted position, damage to the yoke can result.

- Investigate the possibility to alter the PSEU software to remove the opening of the MLG doors (and thus de-pressurising the unlock actuator) as a maintenance indicator of a down lock sensor fault, and show this fault through another means.
- Investigate structural changes that could be made to enable the stab brace to be replaced without partially retracting the MLG.

Landing gear manufacturer:

- A review has taken place of the internal drawings and manufacture of the yoke. It was found that sufficient controls are in place during the machining operation to ensure the proper alignment of the joints.
- The inspection process during manufacturing was reviewed to ensure conformity of the manufactured product with the drawing. It was found that any deviations from the drawings are captured in Quality Notifications (QN's) that are reviewed by the Material Review Board for disposition. On the RH MLG yoke from this aircraft, there were no QN's raised.

Operator:

- A fleet wide check of all PSEU was carried out to determine if there was any history of a down lock sensor faults that caused the MLG doors to stay open. In case of faults found corrective action was taken.
- The PSEU upgrade program (regular PSEU upgrade as a result of AD Number: CF-2016-31R1) was paused until additional checks of the removed PSEU for Down Lock sensor faults and post upgrade check of the Down Lock sensor rigging serviceability were put in place.
- The stab brace installation procedure was enhanced to include a check for any PSEU faults codes whilst manipulating the down lock sensor harnesses.
- Since the distortion in the yoke cannot be determined or measured in situ, it was determined that problems with the free fall check were an identifier for possible problems with the yoke. Attention was given to check for possible indications after stab brace change and scheduled maintenance involving the MLG.
- Following reports of MLG doors remaining open, aircraft is to be removed from service until Down Lock sensor serviceability is established.

2.8 Summary

When flying from the departure airport enroute to Schiphol, the aircraft was flying in sub-zero temperatures (-19˚ Celsius). On approach to Amsterdam Airport Schiphol the aircraft descended to a region with warmer air (+8 ˚ Celsius). Under these circumstances it was found that one of the newly installed MLG proximity sensors was producing faulty information being sent to the PSEU, which subsequently flagged the sensor as faulted.

On final approach to Schiphol the flying crew lowered the MLG for landing. The doors were opened, and the gear was lowered. Because the MLG yoke was twisted, additional friction was present on the hinges holding the gear, and possible force created by the bend yoke put a bending force on the brace assembly. This, in combination with the initial rebound of the stabilizer brace apex from impacting of the apex stops during extension under the wind forces acting on the MLG prevented the brace assembly to go into over centre position.

The deformation of the yoke most likely affected the stabilizer brace's final over centre position after the gear extension, while not affecting the lock link over centre position, as shown by the inability to positively lock the brace during the hangar tests by the investigation team.

Under circumstances where both proximity sensors operate normally, both the MLG aft doors and the unlock actuator will be energized whereby the actuator may aid the brace position itself into the over centre position. Additionally, analysis showed that with one apex joint of the stabilizer brace under centre (as could be expected with the yoke deformed as it was), landing loads at the high end of "normal" can cause the stabilizer brace to fold[9].

As per design, the down lock sensors are driven by the lock link over centre within the stabilizer brace assembly. If there are no anomalies in the MLG and the down lock sensors are rigged per the AMM, then:

- the lock links only achieve their over centre position once the stabilizer brace achieves its over centre position, and
- a 'GREEN' indication in the cockpit means that both the stabilizer brace and lock links are over centre, as desired.

In this event, where the yoke was deformed prior to the accident, it is outside any condition that was within the design specifications.

The forces on the brace assembly were such that it was possible that, despite the stabilizer brace was not in the over centre position, the lock link was. This caused for the MLG indicating lights showing a green light, despite the fact the brace assembly was not over centred, and thus the MLG was down, but not locked.

Since the right hand MLG stabilizer brace lock links became unlocked, once the aircraft landed on the runway, almost immediately after touch down, the weight of the aircraft caused the right hand MLG to collapse, resulting in the accident.

9 Pressurizing the unlock actuator was proven to help in the case of a tire imbalance (Jazz incident in 2014), which loads the stabilizer brace in a different way compared to the static instability condition that the Flybe brace experienced. Based on the static stability analysis presented last year, pressurization of the unlock actuator would likely not have prevented MLG collapse on the Flybe aircraft with the stabilizer brace apex joint(s) starting in an under centre position. Other factors that could have potentially prevented issues during the previous flights were different landing conditions.

CONCLUSIONS

- Maintenance was performed on the night before the day of the mishap flight, during maintenance the MLG brace was replaced. The maintenance crew stated they did not find anything unusual during the installation of the brace.
- After the accident, the newly installed stabilizer brace showed no deformation, nor did the attachment lugs on the yoke or the forward nacelle.
- The PSEU showed several fault codes which were consistent with the condition of the aircraft during the approach and after the incident.
- One of the MLG down lock sensors was found unreliable. The faulty sensor prevented the PSEU logic from closing the aft RH MLG doors and activating the unlock actuator.
- The unlock actuator not being activated prevented the brace being aided to maintain its over centred position by hydraulic pressure.
- The RH MLG yoke was found deformed. Analyses, and the fact no deformation was present on the stabilizer brace assembly, indicate that the deformation on the yoke was present prior to touchdown at Schiphol, and that this deformation was caused when NO stabilizer brace assembly was installed.
- The deformation of the yoke placed the RH MLG in a condition outside the certification state, thereby exposing the RH MLG stabilizer brace assembly to the potential of unlocking.
- The bent yoke caused friction in the MLG yoke and brace combination, which prevented at least one of the two stabilizer brace apex joints from achieving an over centre condition when the MLG was extended prior to landing. Although not designed for this, not hydraulically activating the unlock actuator after the gear was in the down position, prevented the brace assembly from being retained into over centre position.
- Despite the fact the gear was not fully locked, and outside certification condition, three green lights indicated to the crew that the gear was down and locked. Although not noticed by the flying crew, the amber caution light indicating the aft RH MLG were open, most likely was lit during landing.
- The combination of friction caused by the bent yoke, and faulty sensors preventing the unlock actuator to be activated, caused a situation whereby the stabilizer brace of the RH MLG did not get into over centre position causing an instable situation, despite the three LG green lights illuminated.
- During an asymmetric (rolled) touchdown in Amsterdam torsion loads were applied to the MLG, and the MLG strut collapsed almost immediately after touchdown of the RH MLG, causing the accident to happen.

ANNEX 1 – PSEU READ OUT

FLT 00 (Edinburgh to Amsterdam – Incident flight):
NGDRCL Unreasonable FAR. (result of NLG doors being manually opened during/after aircraft recovery)
RGDRCL Unreasonable FAR (result of the RH MLG aft doors remaining open after gear extension)
RGDNLK1 Unreasonable FAR (result of the RH MLG collapse)
RGDNLK2 Prox Sensor Short (most likely caused the failure of RH MLG aft doors to close after RH MLG extension)
RGWOW1 Unreasonable FAR (result of the RH MLG collapse)
RGWOW2 Unreasonable FAR (result of the RH MLG collapse)
Right Main Power Failed (result of the aircraft recovery process, when the main battery -which is connected to the right main power bus- was removed to insert in place of the standby battery, which was depleted after the incident)
FLT 01 (Amsterdam to Edinburgh):
RGDNLK2 Prox Sensor Short (appears to have been intermittent, 'healing' itself since the aircraft cannot be dispatched with MLG aft doors still open)
FLT 02 (Birmingham to Amsterdam):
RGDNLK2 Prox Sensor Short (appears to have been intermittent, 'healing' itself -since the aircraft cannot be dispatched with MLG aft doors still open-)
FLT 03 (codes logged during swap of stabilizer brace and subsequent functional checks)
RGDLK1 Prox Sensor Open
RGDLK2 Prox Sensor Open
Various fuselage doors unreasonable FAR
LGDRCL Unreasonable FAR
RGDRCL Unreasonable FAR
Left Main 1 and 2 Power Failed
Right Main Power Failed
DIN01A Unreasonable FALSE
DIN01B Failed
DIN01D Failed (Landing gear advisory lamp test #1)
NGDN1 Unreasonable NEAR

NGDN2 Unreasonable NEAR
NGLK1 Unreasonable NEAR
NGLK2 Unreasonable NEAR
RGWOW1 Unreasonable NEAR
RGWOW2 Unreasonable NEAR
NGWOFFW1 Unreasonable NEAR
NGWOFFW2 Unreasonable NEAR
FLT 08 (result of MLG aft doors manually opened using alternate release lever in cockpit)
LGDRCL Unreasonable FAR
RGDRCL Unreasonable FAR
FLT 14 (result of MLG aft doors manually opened using alternate release lever in cockpit, and power being manually interrupted)
LGDRCL Unreasonable FAR
RGDRCL Unreasonable FAR
Left Main 1 and 2 Power Failed.
Right Main Power Failed.
FLT 28 (result of MLG aft doors manually opened using alternate release lever in cockpit)
LGDRCL Unreasonable FAR.
RGDRCL Unreasonable FAR.

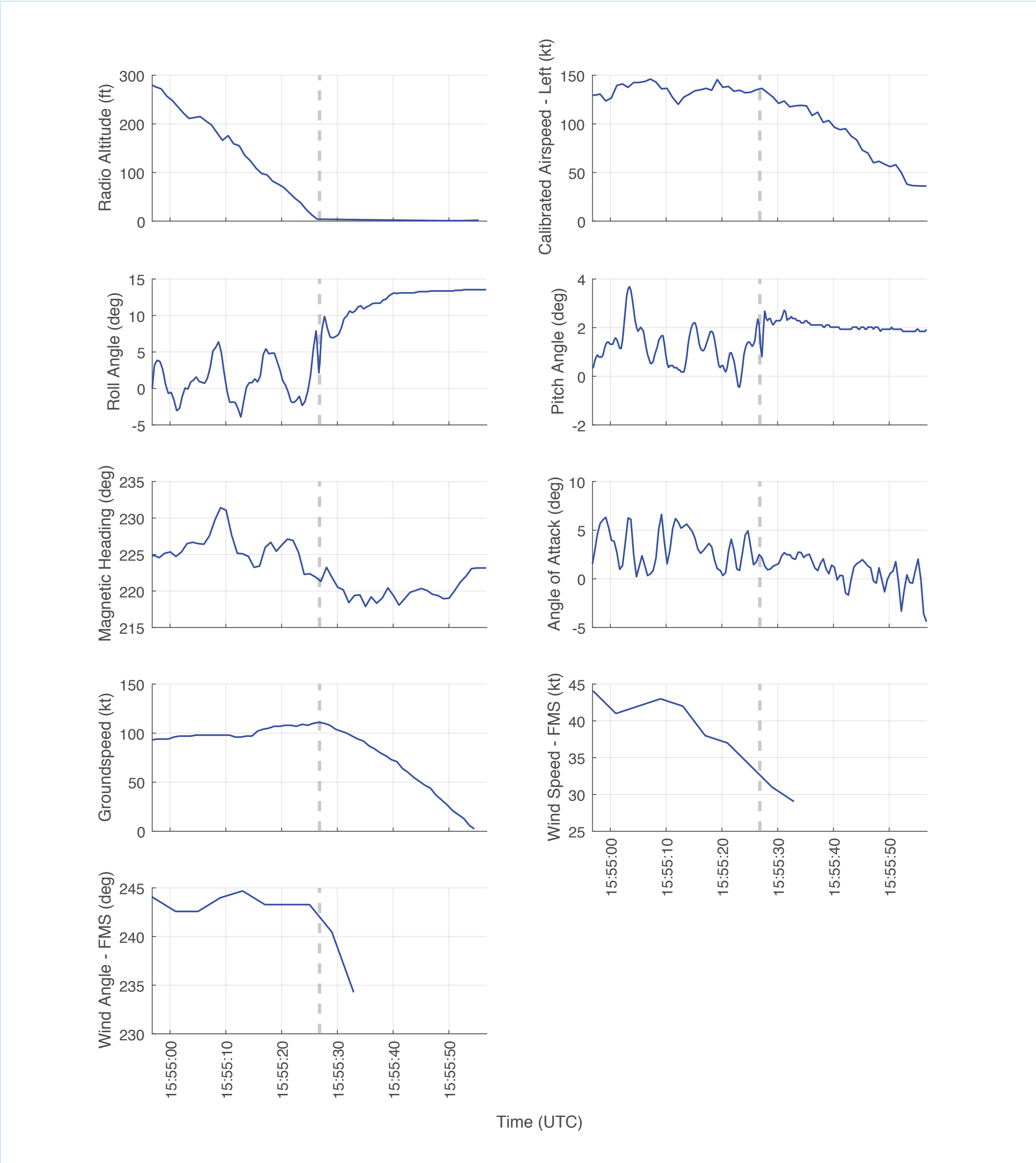

Figure 20: Time-history plot of the aircraft state and wind related parameters as obtained from the decoded FDR data.

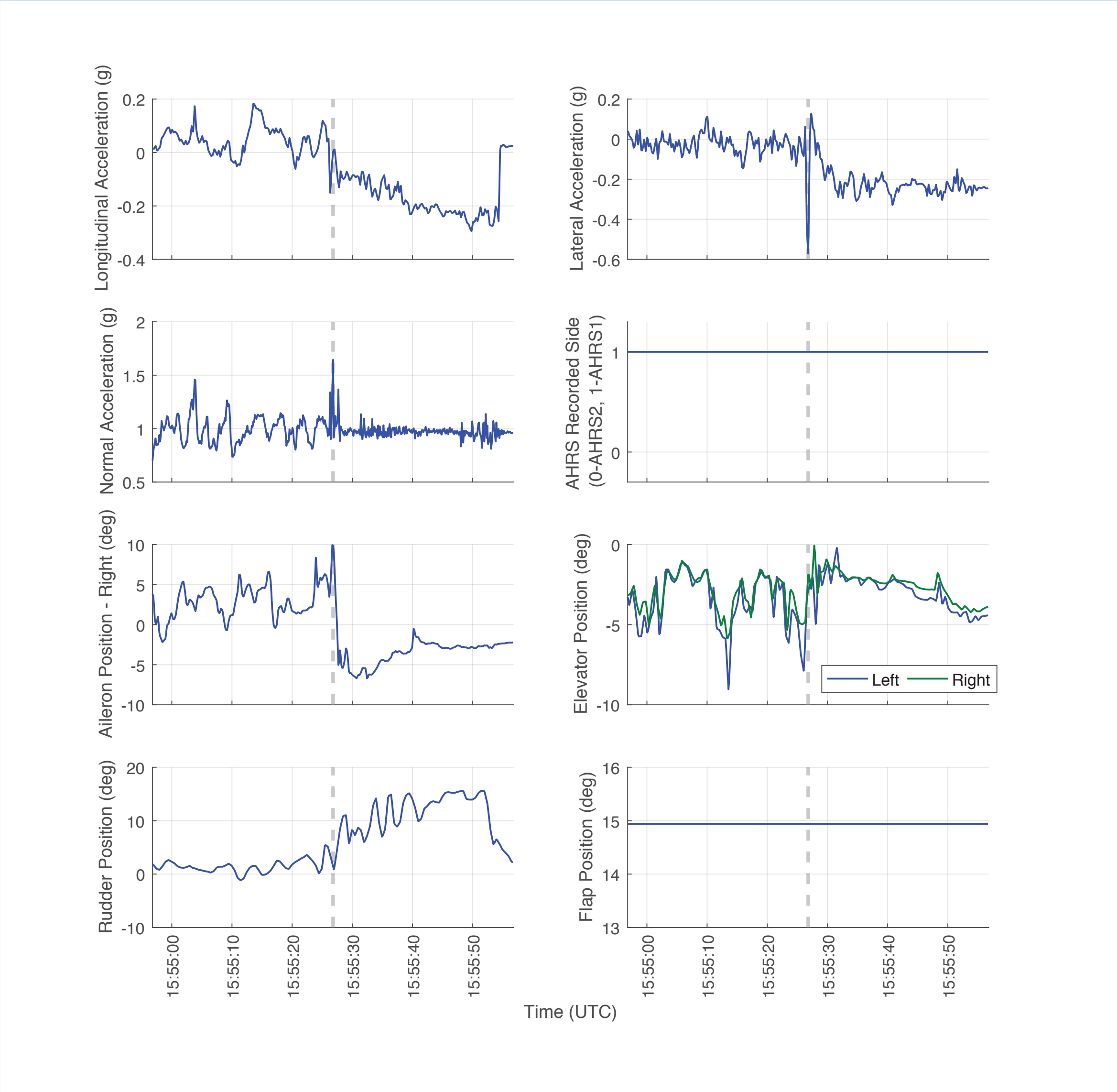

Figure 21: Time-history plot of the linear accelerations and position of the control surfaces as obtained from the decoded FDR data.

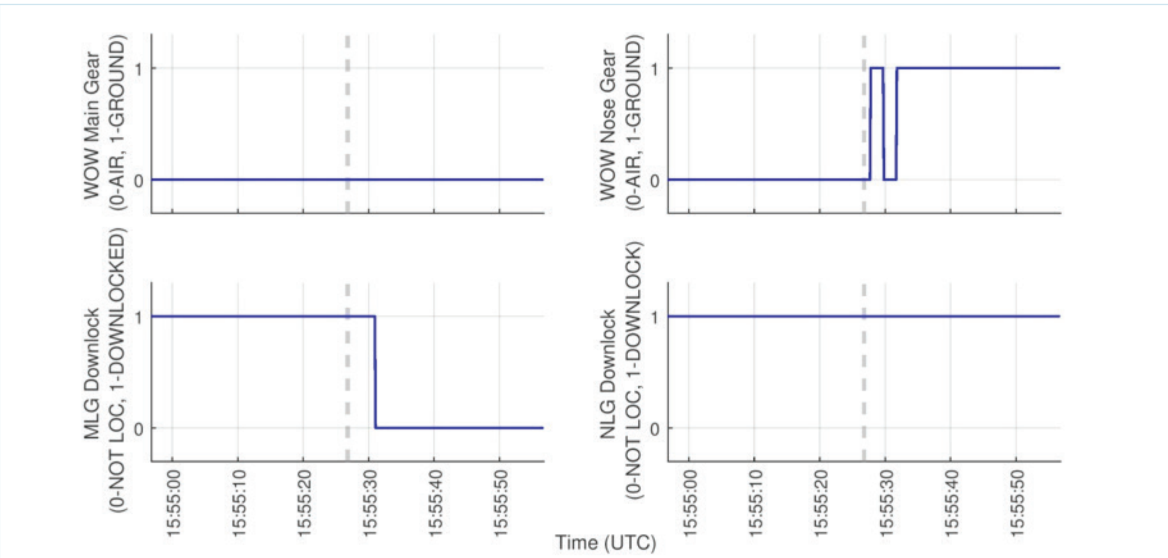

Figure 22: Time-history plot of weight on wheels sensors and gear downlock parameters as obtained from the decoded FDR data.

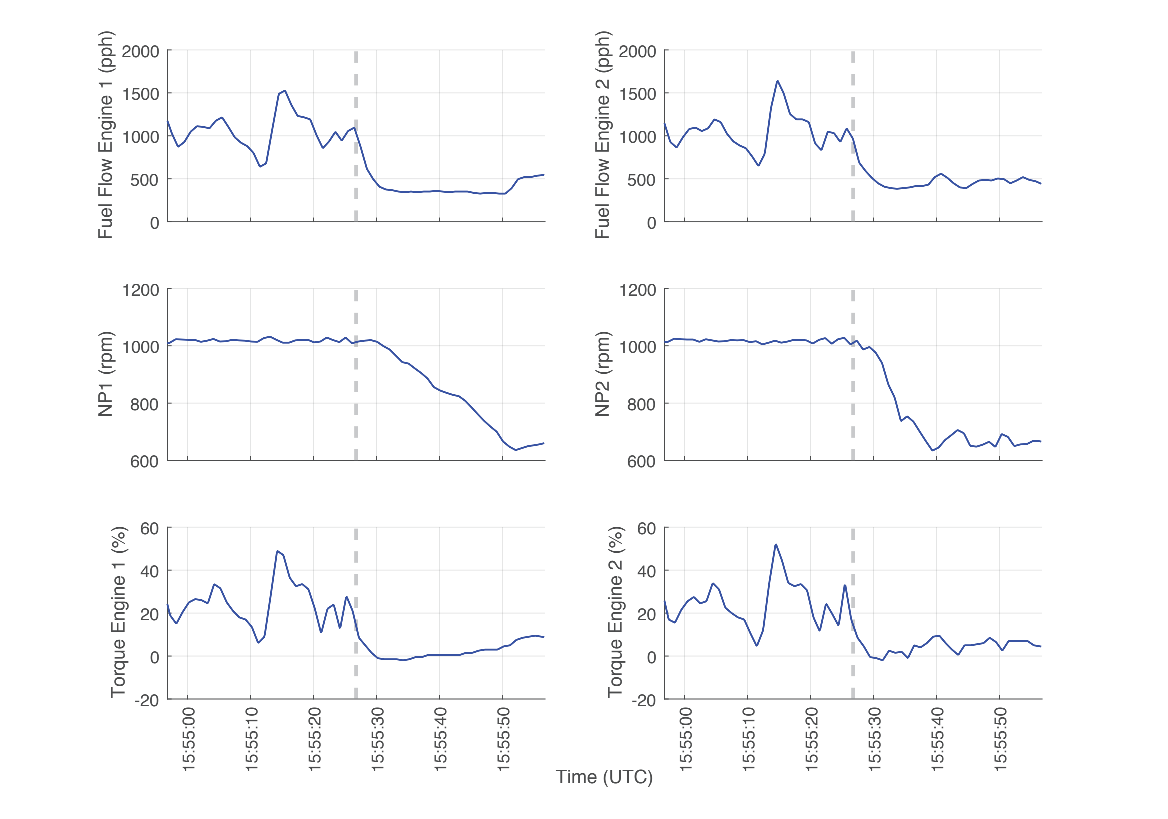

Figure 23: Time-history plot of the fuel flow, propeller rotation velocity and engine torque as obtained from the decoded FDR data.

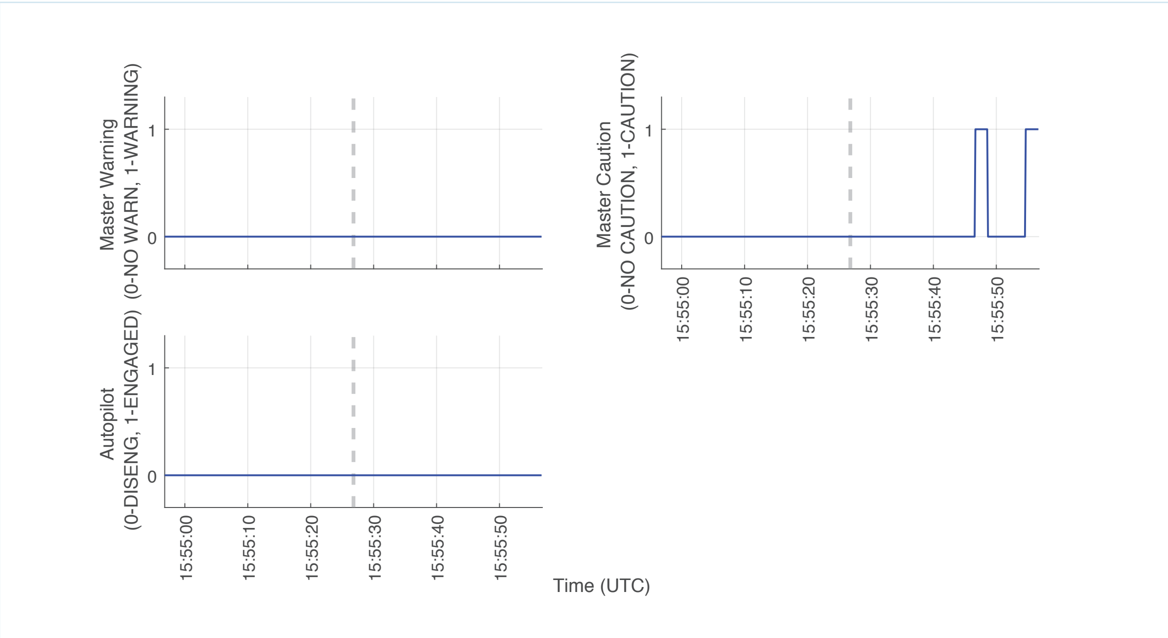

Figure 24: Time-history plot of the fuel master warning, master caution and autopilot engagement as obtained from the decoded FDR data.

ANNEX 3 – GEAR ANALYSES

The dynamic analysis

The analyses was a two-step process:

A landing simulation was conducted with a simplified dynamic model to obtain a time-history of ground loads (i.e. loads exerted on the tire contact points with the ground) applied to the landing gear during the touchdown experienced at Schiphol.
The time-history of ground loads derived from the landing simulation (Step 1) were used to analyze the landing gear dynamic response using a full-gear dynamic model.

Step 1: Landing Simulation

The landing simulation model took into account all key touchdown parameters, including:

- Dynamic weight over the RH MLG,
- Aircraft pitch angle,
- Aircraft roll angle,
- Aircraft descent speed at touchdown,
- Aircraft forward speed at touchdown.

All these parameters were extracted from the FDR data. The landing simulation model captures the time-delay between touchdown of the right hand and left hand tire on the RH MLG, which is caused by the right-wing-down roll angle at touchdown. This model captures the spring-damper behaviour of the landing gear during the in-stroke, and provides accurate prediction of the time-history of ground loads.

Step 2: Full-Gear Simulation

The full-gear dynamic model contained all major deformable components of the MLG (axle, piston, outer cylinder, upper torque link, lower torque link, drag strut, yoke, forward stabilizer brace, aft stabilizer brace, forward lock link and aft lock link) in 3D, and captured the mass distribution and stiffness of the assembly accurately. The time-history of ground loads from Step 1 were used as inputs for the full-gear simulation. The following are to be noted:

- Unlock actuator force resulting from 50 PSIG in both extend and retract chambers (i.e. return pressure) was included in the model. The resulting actuator force was negligible,
- Retract actuator force resulting from 3,000 PSIG in the extend chamber is included in the model (since the retract actuator is pressurized during and after gear extension).

The simulation was conducted for 0.25 seconds from initial contact of the RH tire. This enveloped the time between initial touchdown of the RH MLG and visible movement of the RH MLG shock strut after unlocking from video analysis performed by landing gear manufacturer (which was 0.135 seconds).

Description of elasto-plastic analysis.

The objective of the elasto-plastic analysis was to determine the conditions under which the yoke could suffer permanent deformation, as observed during post-incident inspections. The MLG outer cylinder and yoke were represented as deformable components in 3D, with elasto-plastic properties applied. All other relevant components of the gear were represented in a simplified manner. Two configurations of the gear were examined.

Configuration 1: MLG in the down position. This is the configuration of the MLG in which all landing loads and ground-manoeuvring loads are experienced.

Configuration 2: MLG in a position between up and down positions. This is the configuration of the MLG during a stabilizer brace change (maintenance activity), in transit during gear extension or retraction, or after the gear unlocked during landing on A/C 4136. The stabilizer brace was not included in this model. The following load cases were analysed for these configurations:

- Ultimate landing loads that produce torsion loading on the gear from the certification loads deck (selected based on observed shape of deformed yoke) – Configuration 1 used, with gear set to appropriate stroke.
- Ultimate ground manoeuvring loads that produce torsion loading on the gear from the certification loads deck (selected based on observed shape of deformed yoke) – Configuration 1 used, with gear set to appropriate stroke.
- Ultimate ground-manoeuvring lateral load case that designs key sections of the yoke – Configuration 1 used, with gear set to appropriate stroke.
- Enforced lateral displacement of up to 12 inches at axle – Configuration 2 used, with gear set to zero stroke (i.e. piston fully extended inside cylinder).

Parameters	Flexible nacelle	Flexible nacelle	Rigid nacelle
Axle lateral displacement (in)	-10.5	-11.5	10.5
Axle lateral reaction (kips)	-3.729	-3.901	3.990
Max PEEQ (yoke)	0.01753	0.02206	0.02014
Max PEEQ (aft SB)	0.02219	0.02828	0.04137
Axle centring force (kips)**	0.647	0.893	-1.150

Table 9: results of loading tests. (source: landing gear manufacturer)

*** centring force is load required to centre the shock strut back to original (zero) position*

Loading steps	Flexible nacelle Dy = 10.5″		Flexible nacelle Dy = 11.5″		Rigid nacelle Dy = 10.5″	
SB to AC reactions	IB LH MLG	OB LH MLG	IB LH MLG	OB LH MLG	IB RH MLG	OB RH MLG
Rx (kips)	0.369	-3.729	0.355	-0.527	-0/359	0.190
Ry (kips)	3.102	0.01753	3.241	2.714	-2.481	-3.806
Rz (kips	-4.620		-4.854	4.478	-4.415	4.123
SB to AC displacements	IB LH MLG	OB LH MLG	IB LH MLG	OB LH MLG	NA	
Ux (in)	-0.0318	0.0276	-0.0338	0.0276		
Uy (in)	0.0343	0.0320	0.0330	0.0320		
Uz (in)	0.1231	0.2242	0.1287	0.2242		

Table 10: basic results from loading steps. (source: landing gear manufacturer)

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