SERIOUS INCIDENT

Aircraft Type and Registration:	Bombardier BD-700-1A10 Global 6000, 9H-VJM	
No & Type of Engines:	2 Rolls-Royce BR710A2-20 turbofan engines	
Year of Manufacture:	2013 (Serial no: 9630)	
Date & Time (UTC):	11 December 2019 at 0550 hrs	
Location:	Liverpool Airport	
Type of Flight:	Commercial Air Transport (Passenger)	
Persons on Board:	Crew - 3	Passengers - 1
Injuries:	Crew - None	Passengers - None
Nature of Damage:	None	
Commander's Licence:	Airline Transport Pilot's Licence	
Commander's Age:	53 years	
Commander's Flying Experience:	11,506 hours (of which 3,864 were on type) Last 90 days - 104 hours Last 28 days - 48 hours	
Information Source:	AAIB Field investigation	

Synopsis

The aircraft suffered a nosewheel steering failure shortly after touchdown. During the subsequent landing roll, directional control was lost due to the inadvertent application of right braking and the aircraft departed the runway surface onto the grass.

History of the flight

The aircraft was engaged in ad hoc, long haul VIP charter operations. The pilots involved were both on variable rosters, but they had been operating together since 4 December 2019. They flew to Sao Paulo, Brazil on 7 December 2019 where they spent approximately 48 hours before flying back to Newark, USA on the evening of 9 December 2019. After a rest period of 14 hours the crew reported for the incident duty at 2020 hrs. The aircraft departed Newark at 2230 hrs and made a 50 min transit, without passengers, to Bedford Airport, Massachusetts, USA. The co-pilot was under training and he was Pilot Flying (PF) for the sector to Bedford. The aircraft was serviceable, and no issues were recorded in the technical log.

In Bedford, the aircraft was refuelled, and the catering replenished for the upcoming transatlantic flight. Having embarked the one expected passenger, the aircraft departed Bedford at 0020 hrs with the co-pilot as PF and the commander as Pilot Monitoring (PM). The crew described the flight as being completely routine.

Approaching Liverpool, the aircraft was radar vectored for an ILS to Runway 27 which is 2,285 m long with a grooved asphalt surface. The crew reported that Liverpool ATC vectored them to the approach centreline quite early, but they stated that there were no difficulties with the approach. The 0520 hrs meteorological report gave a wind 190° at 9 kt, visibility greater than 10 km and a cloudbase of 3,400 ft aal. The runway surface was damp in all three sectors.

The aircraft was on the centreline of the approach at approximately 7 nm and achieved stable approach criteria by 1,000 ft aal. The approach was flown with Autopilot (AP) engaged until approximately 600 ft aal. At that point the PF deselected the AP and continued with a manually flown approach in visual conditions. The reference speed for the approach was 115 kt.

The commander described the landing as good. The touchdown was gentle, and the PF gradually lowered the nosewheel onto the runway. The autobrakes were not selected as the crew planned to brake manually, and the co-pilot recalled that the intention was to use Exit E from the runway (Figure 1). The co-pilot did not brake hard and set approximately 50% reverse thrust. In the early stages of the landing roll the crew did not recall any sense of the aircraft deviating from the centreline of the runway. It is the operator's SOP for the PM to call '80 kt' as the aircraft decelerates through that speed and for the commander to take over control of the aircraft as it decelerates below 60 kt. However, before 80 kt was reached, the commander noted the aircraft deviating to the right and took control. At 100 kt, the FDR data showed that a MASTER CAUTION was activated, associated with a NOSE STEER FAIL caution message displayed on the Engine Indicating and Crew Alert System (EICAS). While there is an audio warning associated with the appearance of a MASTER CAUTION, neither pilot recalled hearing it sound.

Once he took control, the commander instinctively applied left rudder to try and keep the aircraft on the centreline. He quickly reached full left rudder deflection[1] but could not keep the aircraft straight. At this point he recalled noticing the NOSE STEER FAIL caution on EICAS. The co-pilot recalled feeling it was likely that the commander was trying to steer into Exit E (Figure 1). The commander did not recall making any use of differential braking to correct the aircraft's path. Neither pilot recalled making any significant braking effort nor any sensation of the antiskid system operating.

Footnote

[1] The pilots stated during interview that the only time they had previously used full rudder deflection was in training for engine failures during takeoff.

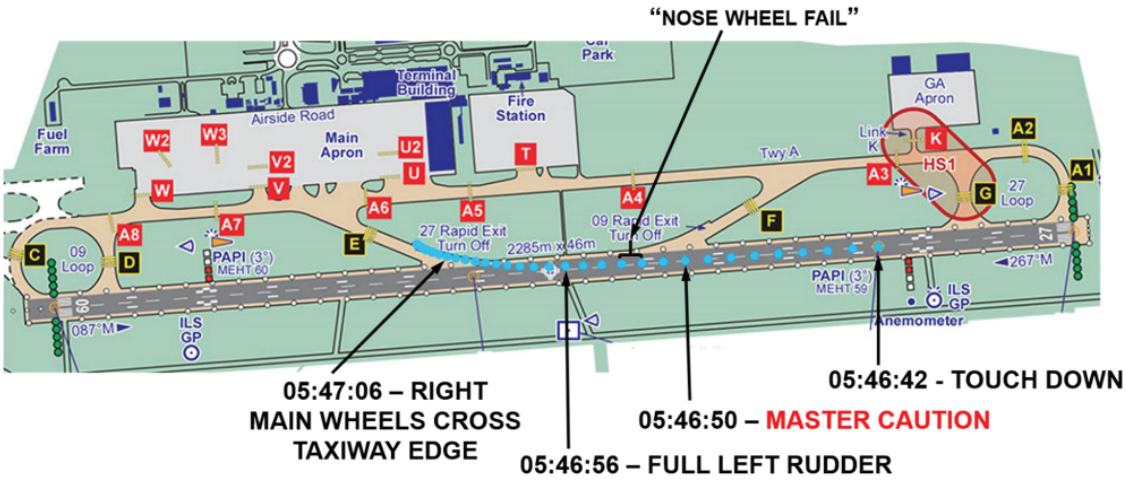

Figure 1

Liverpool Airport with the aircraft's ground track shown as blue dots
(at one second intervals)

As the speed reduced, the aircraft turned more rapidly to the right and the commander was unable to keep the aircraft on the paved surface. The commander did not recall the speed at which the aircraft left the paved surface, but the co-pilot believed it was approximately 50 kt and he recalled seeing the NOSE STEER FAIL caution on the EICAS before the aircraft left the runway.

Once on the grass, the aircraft rapidly came to a halt. The crew informed ATC of their situation, started the Auxiliary Power Unit (APU), retracted the flaps and completed the aircraft shutdown checklist. The airport fire services were quickly on scene and, following a discussion with them by radio, the commander shut down the APU. During the shutdown checklist the crew noted that the brake temperatures were lower than normal. The temperature is indicated on a scale of 0 to 39 and the right outboard brake was hottest although it only indicated 2. The scale indicates red if the value exceeds 16.

Once the aircraft was shut down, the crew and passenger vacated via the forward air stairs door.

Incident site

The aircraft had left the runway just before the start of runway rapid exit turnout (Exit E) to the right. It travelled approximately 30 m on the grassed area and its landing gear wheels sank into the topsoil and brought the aircraft to a stop. Mud and soil encased the lower parts of the landing gear (Figure 2). The flaps and slats were up, and mud and soil had been thrown upwards to become entrapped within the flap track mechanisms and fairings. Mud was also present on the wing leading edges and wheel bays and there were mud spatters on the engine intake rings.

Figure 2

9H-VJM on the soft ground

The aircraft had left a pair of faint right mainwheel tyre tracks on the runway surface up to the point where it had run on to the grass. There were no discernible marks made by the left mainwheels or nosewheels.

The aircraft had been shut down and made safe; the first responders had inserted the ground lock pins. All the tyres remained inflated and there was no evidence of any fluid leakage. At the time of the incident the aircraft contained approximately 5,000 kg of fuel.

Apart from the deep wheel tracks in the grass there was no damage to any of the airport signage or fixtures.

Heavy recovery vehicles were used to recover the aircraft backwards on to the runway. The soil contamination was hosed off by the airport fire service and an initial inspection of the landing gear was carried out to ensure that it was safe, before the aircraft was towed to a secure hangar.

Recorded information

Following the event, the aircraft's flight data recorder (FDR) and cockpit voice recorder (CVR) were removed from the aircraft to be downloaded at the AAIB. A copy of the quick access recorder (QAR) data (containing the same data recorded by the FDR) for the event flight was also provided by the operator. Data for the event is plotted in Figure 3.

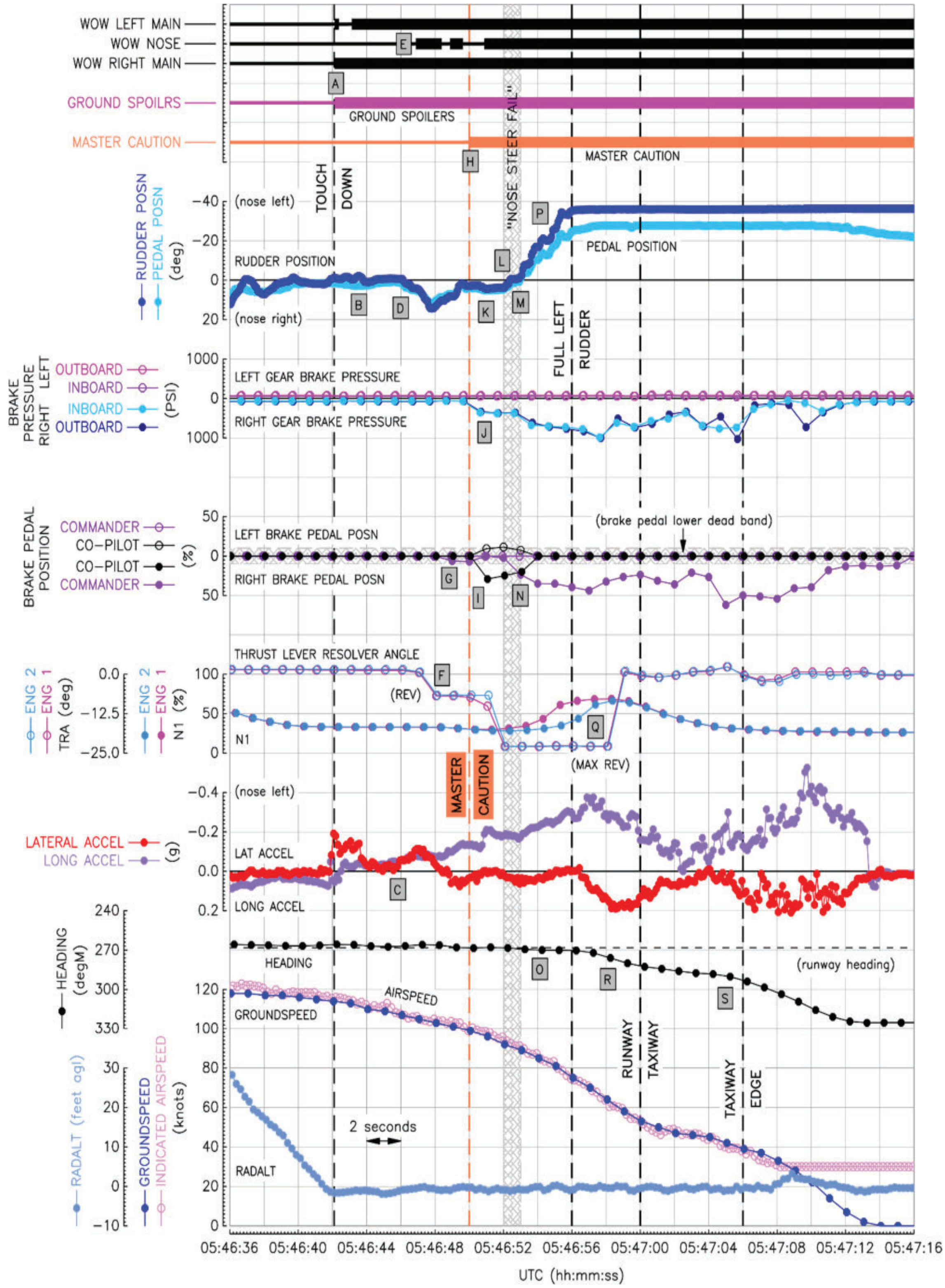

Figure 3

Recorded data for the landing

The key points from Figure 3 are:

- 0546:42 – the aircraft touched down on mainwheels [A] slightly right wing down and nose left. The airspeed was about 115 KIAS and the ground spoilers deployed.
- Small right rudder pedal inputs[2] made [B] to straighten up the aircraft (still on just the main gear).
- The aircraft started to turn left [C] – one of the crew immediately applied right rudder pedal to counter this movement [D].
- The nosewheel touched down nearly five seconds after initial ground contact of the main wheels [E].
- The thrust levers [F] were pulled back from IDLE to REV[ERSE].
- A small input on the commander's right brake pedal is recorded [G] but within the brake pedal's dead band[3] so brake pressure was not applied. The input lasted about two seconds.
- The nosewheel 'bounced' twice over a period of four seconds during which a MASTER CAUTION occurred (with corresponding illumination of the MASTER CAUTION button, and a single chime heard on the CVR recording) [H].
- The co-pilot applied a small input to the brake pedals – left travel is in the dead band and just under one quarter travel on the right [I] so only right gear brakes were applied [J]. A corresponding input on the right rudder pedal is also recorded [K].
- Two seconds after the MASTER CAUTION is issued, the commander verbally announced a "NOSE STEER FAIL" (heard on the CVR recording) [L] just as the thrust levers were pulled back to MAX REV[ERSE]. A left rudder pedal input was made [M] (co-pilot still applying right brake) with a corresponding right brake pedal input by the commander [N].
- The aircraft started to veer to the right [O] and increasing amounts of left rudder (and right brake by the commander) were applied. Maximum rudder deflection was reached after four seconds [P] and no further braking by the

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Footnote

[2] The rudder pedal input sensor measures the movement of the link between the pedals for commander and co-pilot and so does not discriminate between whose pedal are being depressed. The recording of rudder pedal force was not a requirement of the EASA regulations under which 9H-VJM was operating. Note that for aircraft to meet one of the requirements of the FAR Part 135.152 (flight data recorders), the aircraft manufacturer issued Service Bulletin 700−31−6002 in June 2012 (revised November 2016) to install eight force transducer units (FTU) and activate the crew force measuring system (CFMS).

[3] The brake pedal movement has a dead band from 0% to10% and from 80% to100%. Between these bands, the brake pressure rises from 0 psi to 3,000 psi.

co-pilot was recorded from this point. From the CVR recording, for the middle two of these four seconds, the commander can be heard straining, halfway through which the co-pilot started to say "YOUR". As full rudder deflection was reached the co-pilot said what sounds like "YOUR STICK".

- A two-second delay is recorded between the engines each reaching the N_1 corresponding to maximum reverse thrust, with the left engine leading [Q].
- At about 70 kt groundspeed (when full left rudder was reached), the aircraft started to veer more rapidly to the right [R] onto the taxiway before veering further to the right [S] over the edge of the taxiway, which the right main gear crossed at about 40 kt, 10 seconds after full left rudder was applied.
- 0547:14 – the aircraft came to a stop 24 seconds after the MASTER CAUTION was issued; the MASTER CAUTION had remained illuminated throughout.

Aircraft information

The Bombardier Global 6000 is a twin rear-engined long range business jet with a capacity to carry up to 13 passengers. It has a maximum takeoff weight of 45,132 kg and a maximum fuel load of 20,400 kg.

Landing gear

The aircraft is fitted with a tricycle landing gear with dual wheels fitted on the nose and main landing gear assemblies. The landing gear is retracted and extended by electrically controlled hydraulic actuators and is fitted with a manual release system for emergency extension.

Nosewheel steering (NWS) system

The landing gear is fitted with a steer-by-wire electronically controlled NWS. Steering is controlled from the cockpit via the rudder pedals and a handwheel (also known as a tiller). Steering is controlled and monitored by the steering control unit (SCU).

Nosewheel articulation is provided by two cylinder and piston steering actuators mounted on the upper nose landing gear forging. They apply force to the left and right side of a steering cuff which carries the upper arm of the torque link. This imparts leverage and rotation into the lower arm of the torque link attached to the base of the nose shock absorber assembly inner piston. The actuators are sequentially controlled to prevent the actuator pistons going into over centre geometric lock when the cuff is at its full range of rotation. A linear variable differential transducer (LVDT) is fitted in each actuator to provide a nosewheel positional feedback signal.

The nose landing gear is fitted with two weight-off-wheel proximity sensors mounted to detect target plates fitted on the upper torque link arm. They are configured to sense when the aircraft is 'weight-off' and input to the landing gear electronic control unit (LGECU).

During ground handling, when the aircraft is in an unpowered condition, the upper and lower torque link arms can be disconnected by the removal of a pin to prevent damage to the actuators and hydraulic system. This allows rotation of lower shock absorber piston and nosewheel axle assembly when attached to a towing arm, whilst the cuff and actuators remain stationary.

Hand steering

The handwheel is situated on the left side of the cockpit on the pilot side console. It can provide nosewheel articulation of 75° either side of centre, this corresponds to 80° of handwheel movement between the stops which limit the movement. The handwheel is viscous damped to provide self-centring and artificial feel. This also provides a positive breakout force and a speed sensing damping force. The handwheel shaft movement drives a rotary variable differential transducer (RVDT) which converts handwheel movement to an electrical steering command input to the SCU.

A fault is recorded by the SCU if, during an air-to-ground transition, the position of the handwheel is beyond 7.5° from neutral.

Rudder steering

Movement of either set of rudder pedals actuates an RVDT attached to the top of the pivot shaft on the co-pilot's rudder assembly. Rudder pedal steering authority is 7° (+2°/-0°) either side of centre corresponding to full rudder pedal deflection.

Operation

The NWS is activated by a two position OFF/ARMED toggle switch fitted on the landing gear control panel. When selected to ARMED, it provides DC power to the SCU and a built-in test (BIT) equipment check is automatically and continuously carried out by the SCU to verify the integrity of the system.

NWS faults are indicated as NOSE STEER FAIL on the EICAS. A fault code to aid fault diagnosis and rectification can be downloaded from the SCU if required.

The following set of conditions are required for the NWS system to operate using either the rudder pedal or the steering handwheel. The nose landing gear should be down and locked, the weight-off-wheel switches should be 'open'[4] and the NWS switch set to the ARMED position. Then, providing the BIT is satisfactory, the SCU energizes a solenoid selector valve and hydraulic pressure from the gear down system is reconfigured to provide steering. When a steering input is received from the rudder pedals or handwheel and summed with the feedback signal, an electrohydraulic servo valve (EHSV) allows pressure to the actuators to rotate the nosewheels towards the required position. As this position is approached, the LVDT feedback signal is received by the SCU which then signals a cessation of movement via the servo valve. Figure 4 shows a schematic of the NWS.

Footnote

[4] The weight-off-wheels switch is described as open in this case meaning the proximity sensor target is out of the sensor range and has signalled the LGECU that the nose landing gear and wheels are on the ground supporting a proportion of the aircraft weight.

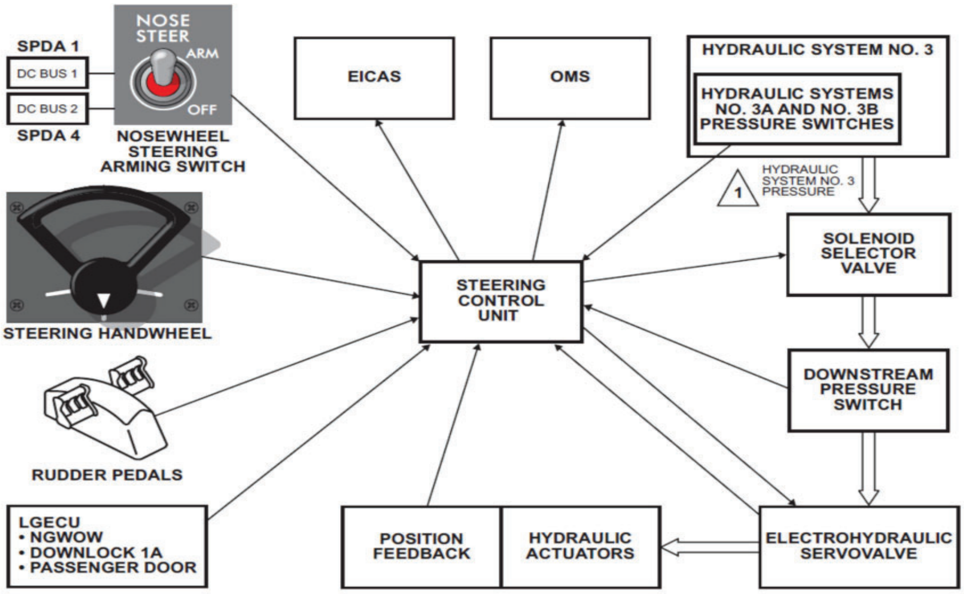


Figure 4

NWS schematic

With NWS selected OFF, or in a failure condition, the nosewheel reverts to free caster. In this condition, hydraulic pressure is blocked to the actuators, but free flow is provided between the actuator supply and return thus allowing unrestricted actuator piston extension and retraction. Nosewheel shimmy damping is provided through a hydraulic compensator that maintains pressure on both sides of the steering actuators when the steering is off.

Wheel brakes

The aircraft is fitted with a brake-by-wire system with each mainwheel fitted with a hydraulically operated carbon fibre disc brake pack. The brake hydraulic system is partitioned with the No 2 hydraulic system supplying the inboard packs and the No 3 hydraulic system supplying the outboard packs.

The integrated brake-by-wire system includes antiskid, autobrake, parking and emergency braking capabilities. There are duplex channels within the control system which normally work collectively but each channel is capable of full brake and antiskid control.

The brakes are applied when the upper part of the rudder pedal is depressed. This mechanical movement is sensed by two pedal position transducers, LVDTs, which produce an electrical signal to the brake control unit (BCU). Pedal displacement is resisted by a pair of springs designed to give feel to indicate to a pilot how hard the brakes are being applied.

The brake control system logic includes a 'dead band' of brake pedal movement within the pedal travel range. It allows 10% of brake pedal movement before any brake pressure is applied. Full maximum pressure braking is achieved at 80% of brake pedal travel, the remaining 20% of travel has no additional effect.

Hydraulic power system

The aircraft is fitted with three hydraulic systems which operate at 3,000 psi. Landing gear extension / retraction and wheel brakes are powered by the No 2 and No 3 systems. The NWS system is powered by the No 3 system from the nose landing extension circuit.

Aircraft examination

Despite departing the paved surface, examination of the aircraft found no pre-existent or resultant damage to the aircraft structure, landing gear, wheels, tyres and brakes. Although there was some evidence of mud spatter on both engine intake leading edges, the engines were undamaged.

The main landing gear's shock absorber extension was correct. The brakes' wear pins showed the brake packs were within limits; tyre wear was unremarkable and consistent with normal usage. The nose landing gear was in good condition and its shock absorber was also correctly extended; the tyres were unworn and correctly inflated.

The CVR and FDR were removed for download. The NWS SCU was removed from the aircraft and its data downloaded for analysis. The EICAS displayed a NOSE WHEEL STEER caution message which the Onboard Maintenance System details as:

> *'Steer by wire system fault 325014DWY – indicates loss of nose wheel steer nose wheel goes to free caster 11Dec2019 0545 – 1 FAULT.'*

Using external electrical power, the hydraulic systems were energised and, with the ground movement pin removed from the NLG torque link, a NWS sense and range check was carried out. During this testing the NWS system operated correctly using the handwheel and the rudder pedals. No additional faults were recorded on the EICAS or on the status display of the SCU.

The rudder and braking systems were also functionally checked. The rudder had full range of movement and operated in the correct sense. The wheel brakes also operated correctly and showed brake pressure correctly in proportion to pedal deflection with either simultaneous or differential braking.

Checks were also carried out to establish the relationship between full rudder pedal displacement and pilots' seat positions, and the potential effect on the brake pedal. This showed that, with the seat adjustment towards the forward end of its travel, there is the possibility that a pilot could inadvertently apply brake pedal movement in excess of the 10% dead band and this would result in brake pressure being applied.

Fatigue

The possibility of fatigue was investigated because the incident occurred during the early morning when the pilots may have been awake for 16 hours or longer. The fatigue investigation considered: sleep and roster history, biomathematical modelling, interviews and the cockpit voice recording.

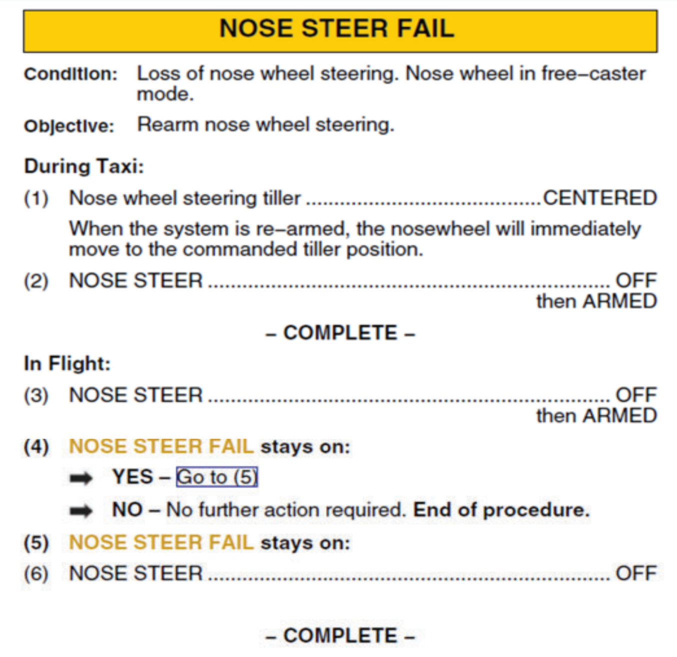
The co-pilot's history did not suggest any fatigue risk factors. The commander's history and the results of biomathematical modelling[5] suggested the commander may have been affected by fatigue due to reduced sleep duration on the night before the incident, working in the window of circadian low and being 'out of phase' in terms of circadian rhythm and sleeping times. However, although the CVR featured some audible symptoms of fatigue and discussion of the topic during the cruise phase of the flight, from the approach briefing onwards, both pilots sounded alert and engaged. In particular, the commander could be heard actively monitoring and coaching the co-pilot under training.

Organisational information

Neither the pilots Type Rating Course nor the operators recurrent training at the time of the event contained practical experience of steering the aircraft at high speed with the NWS failed. The Flight Crew Operating Manual (FCOM) states:

> *'When the steering system is disarmed or with no WOW signal, the nosewheel steering reverts to free caster and shimmy damping to ensure stability within the nosewheel circuit. In the free caster mode of operation, steering is accomplished only through differential braking and differential thrust'.*

The NOSE STEER FAIL Quick Reference Handbook (QRH) drill (Figure 5) is exercised in the simulator during type rating training but at taxying speeds and only commanders undertake the exercise. The QRH drill has sections for both airborne and on the ground.



NOSE STEER FAIL

Condition: Loss of nose wheel steering. Nose wheel in free–caster mode.

Objective: Rearm nose wheel steering.

During Taxi:

(1) Nose wheel steering tiller ....CENTERED

When the system is re–armed, the nosewheel will immediately move to the commanded tiller position.

(2) NOSE STEER .... OFF then ARMED

– COMPLETE –

In Flight:

(3) NOSE STEER .... OFF then ARMED

(4) NOSE STEER FAIL stays on:

➡ **YES –** Go to (5)

➡ **NO –** No further action required. **End of procedure.**

(5) NOSE STEER FAIL stays on:

(6) NOSE STEER .... OFF

– COMPLETE –

Figure 5

Nose Steer Fail checklist

Footnote

[5] The commander's sleep and roster history were assessed using the SAFTE-FAST biomathematical fatigue model. This model considers duration of duties, timing of duties, circadian rhythm, sleep duration and sleep inertia.

The drill is initiated following the appearance of the NOSE STEER FAIL caution on the EICAS. The QRH indicates that, with the caution present, the nosewheel is in free castor mode and the objective of the drill is to re-engage the NWS. The drill does not offer any handling advice nor is it a a memory item. Flight crews would not be expected to consult the QRH in such circumstances as this event. Should the drill fail to recover the system, it states to select the system to OFF. It is permissible to dispatch with the NWS system inoperative under the terms of the Global 6000 MEL[6] and, in such cases, the AFM (Aircraft Flight Manual) Supplement 14 contains handling advice.

Tests and research

Manufacturer's testing

The initial testing revealed no specific failure or malfunction of any individual component within the NWS. Therefore, the following components were removed and returned to the OEM for further testing:

- SCU
- Shock Strut
- Drag Brace
- Manifold Assembly
- EHSV
- LH Steering Actuator (LVDT)
- RH Steering Actuator (LVDT)
- SSV
- Handwheel (Tiller)
- Rudder RDVT

The SCU fault memory contained three specific codes that were likely to be associated with the incident landing: 170 handwheel RVDT, 015 air to ground mode command and 173 left feedback LVDT.

Of the components tested above, two items were found to have faults as indicated by the SCU:

- The handwheel did not pass the null position test but showed a small voltage when returning from 20° CCW which would have resulted in a 0.42° steering offset to the left. In addition, the SCU also detected a 7.5° handwheel offset whilst in the weight-off-wheels condition but this would not have caused the NWS to go into free caster.

Footnote

[6] Dispatch with the NWS Inoperative is permitted under transport Canada and EASA Regulations. It is not permitted under FAA Regulations.

- Both steering actuator LVDTs showed insulation resistance values out of the required range. They were found to be 8 megaohm and 63 megaohm respectively when they should have been ≥ 100 megaohm. This was consistent with previous actuator LVDT faults on other aircraft of this type and is known to be caused by the ingress of moisture. It is also known that this failure mode tends to be a gradual degradation and can be intermittent. However, when either steering actuator LVDT is below limits, it is detected by the SCU BIT sequence and so causes the NWS to go to free caster. Moisture ingress has been addressed by improving the LVDT sealing on later build standard steering cylinders.

Simulator testing

The AAIB conducted an exercise in a Global 6000 simulator to examine the pilot tasks and workload in handling the aircraft on the ground following a NWS failure. The exercise was carried out with the assistance of a TRE/TRI from the operator and a CAA Flight Inspector and, before it commenced, the information in the QRH and MEL relating to the NWS was discussed.

The exercise began with normal ground operations to familiarise the AAIB Inspector with the aircraft. The NWS was then “failed” and a number of taxiing exercises carried out. While it is difficult to steer smoothly, the steering task is straightforward and intuitive. Use of pressure on both brakes against applied thrust, with steering by differential braking makes the aircraft motion smoother, although it does increase brake temperature. The exercise included turns on taxiways and 180° turns on the runway. Both the Global pilots present advised that, due to the reduced precision when steering with the NWS OFF, they would not taxi the aircraft into confined parking areas but would elect to be towed.

A series of simulated landings were carried out, initially with the NWS operational and then with it failed. This exercise was conducted with a variety of crosswinds up to 29 kt. In each event it was relatively straightforward to control the aircraft with a combination of rudder and differential braking.

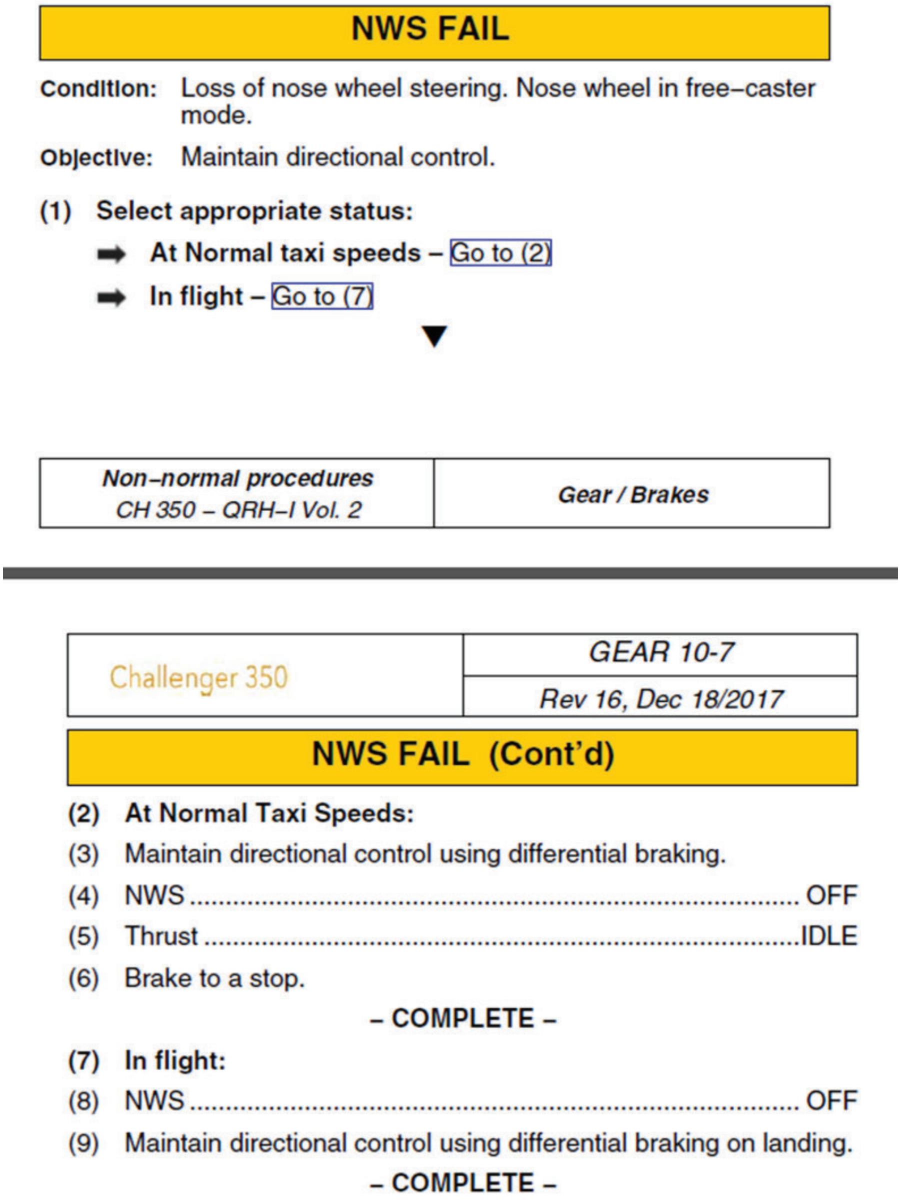
The final exercise was to look at the effect of inadvertent braking. The brake pedals do not need much pressure applied to cause enough movement to result in brake pressure being applied. With full scale rudder pedal deflection applied, the articulation of the opposite foot can apply pressure on the brake pedal and, unless the pilot is conscious of this effect, it is relatively easy to inadvertently apply braking which opposes the sense of the rudder deflection.

For the final series of exercises the aircraft was accelerated to 130 kt on the ground. Then approximately half deflection brake pedal movement was applied to one side and the throttles retarded to idle. During the deceleration, only rudder was used to try and maintain aircraft direction. This was adequate at high speed but, by approximately 80 kt, full scale rudder deflection was insufficient to overcome the effect of the brake.

With the inadvertent braking still applied, the exercise was repeated with the addition of braking applied in the same direction as rudder deflection. Even with the inadvertent braking still applied, the aircraft could be readily controlled on the centreline with rudder and differential brake.

Other information

Other aircraft types produced by the manufacturer and which have similar NWS systems, specifically mention in the QRH and AFM procedures the need to use differential braking to steer in the event of NWS failure. An example of the procedure is at Figure 6.



NWS FAIL

Condition: Loss of nose wheel steering. Nose wheel in free–caster mode.

Objective: Maintain directional control.

(1) Select appropriate status:

➡ **At Normal taxi speeds –** Go to (2)

➡ **In flight –** Go to (7)

▼

Non–normal procedures *CH 350 – QRH–I Vol. 2*	***Gear / Brakes***

Challenger 350	*GEAR 10-7* *Rev 16, Dec 18/2017*

NWS FAIL (Cont'd)

(2) At Normal Taxi Speeds:

(3) Maintain directional control using differential braking.

(4) NWS .... OFF

(5) Thrust .... IDLE

(6) Brake to a stop.

– COMPLETE –

(7) In flight:

(8) NWS .... OFF

(9) Maintain directional control using differential braking on landing.

– COMPLETE –

Figure 6

NWS Procedure for Challenger 350

The manufacturer agreed that the disparity of information between aircraft types on differential braking was unsatisfactory and has undertaken to amend the QRH and Non-Normal Procedures of the AFM for the Global 6000 to provide direct guidance to flight crew on the use of differential braking.

Analysis

Engineering analysis

The component testing of the NWS and associated components showed that the NWS had gone into free caster, as it was designed to do when a fault is detected. It is most likely the NWS fault was caused by either or both steering actuator LVDTs having low insulation resistance values. The handwheel faults detected on test are not considered to have caused any difficulty in controlling the aircraft and would not have caused the NWS to go into free caster.

Handwheel movement is not recorded separately but did show as an offset fault in the SCU beyond 7.5° which would have occurred during one of the weight on/off/on wheels transitions of the nosewheel during touchdown. The commander did not recall operating the handwheel during the event. However, with the NWS system in free caster, any subsequent movement of the handwheel during the rollout would not have had any effect and so is not relevant to the loss of directional control that occurred during this event.

The BIT detected a fault approximately three seconds after the nosewheels initially contacted the runway. The NWS fault did not inhibit the directional control of the aircraft afforded by either the rudder or differential braking.

Operations analysis

There were some fatigue risk factors for the commander, so the investigation considered whether these influenced the course of events. Despite disruptions to sleep and circadian rhythm that are typical of long-haul pilots working at night, the speed of the commander’s reaction to the aircraft’s change of direction and a detailed review of the CVR, showed that he was actively engaged in the task and capable of a fast reaction. On balance, it is unlikely that fatigue was a factor in the commander’s handling of the situation.

For the approach and landing the co-pilot under training was PF. The approach and landing were uneventful, and the co-pilot retained control for the initial stages of the landing roll. The NOSE STEER FAIL caution illuminated approximately eight secs after touchdown, accompanied by its audio tone, and it was acknowledged by the commander two seconds later. Shortly after this, the commander took control of the aircraft when he noticed it turning right from the runway centreline. This was unexpected, so the commander’s posture on the pedals may not have been ideal and he inadvertently applied some right braking, as shown on the recorded data. He instinctively and rapidly applied full left rudder to try and control the aircraft’s direction. This was briefly effective but, as the speed decayed, the rudder’s effectiveness reduced, and the aircraft continued to turn right due to the effect of the right brake still being applied.

The commander was unaware that he had applied pressure on the right brake pedal. The pedal forces are very light, and it is unlikely the commander would have felt much, if any, feedback from it. His expectation was that rudder pedal movement would control the aircraft's direction. When this did not occur, the commander would have needed to recognise the inadvertent braking and either take his foot off the right brake pedal or start to use differential braking to control the aircraft. The time between the aircraft starting to veer right even though full left rudder was applied and departing the runway was approximately four seconds. He had not trained in the use of differential braking at high speed and thus its use did not immediately occur to him. Relevant training may have afforded the commander a rehearsed response that he might have been able to implement in this limited time. He reacted to the situation he was presented with based on instinct and, with all his attention on trying to keep the aircraft straight, high workload and lack of time prevented him from considering an alternative diagnosis.

Conclusion

As a result of a fault, the NWS went into free caster shortly after touchdown. During the subsequent landing roll, directional control of the aircraft was lost, and the aircraft departed the right side of the runway and onto the grass. The commander, in applying left rudder to try to keep the aircraft straight, had inadvertently applied some right braking. As the aircraft slowed, full left rudder was unable to counteract the effect of this braking.

Safety action

Following the event, the operator took the following safety actions to address the issues of inadvertent brake application and use of differential brake for steering at high speed:

> It issued a Safety Alert to all its pilots which included the following:
>
> '*we would like to recommend all pilots, at the first occasion and when on the ground at parking on board of the airplane, to apply FULL rudder deflection. At full rudder deflection one should check if both brakes can be pushed. In addition, notice that the opposite rudder pedal moves physically closer to your body, if you feel the pressure of the closer pedal increasing and if you apply any unwanted brake pressure due to the position of your shoe on the pedal, the pedals/seating position should be adjusted. This should be checked in the normal seating position with the respective shoe position adopted for takeoff and landing.*'
>
> In its Training Syllabus for 2020 the operator has included a failure of the NWS system after landing as a preferred malfunction scenario.

The aircraft manufacturer agreed that the disparity of information on differential braking between its aircraft types was unsatisfactory and also that training for NWS failures at high speeds could be beneficial. As a consequence, the aircraft manufacturer has stated it will:

> Amend the QRH and Non-Normal Procedures of the AFM for the Global 6000 to provide direct guidance on the use of differential braking.
>
> Recommend that appropriate training providers introduce training for takeoff and landing without NWS into the Type Rating and Recurrent Training programmes.
>
> Include information in the FCOM regarding the possibility of inadvertent brake application with rudder pedal deflection and issue a bulletin to all operators to increase awareness of this issue.

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GLOSSARY OF ABBREVIATIONS

aal	above airfield level
ACAS	Airborne Collision Avoidance System
ACARS	Automatic Communications And Reporting System
ADF	Automatic Direction Finding equipment
AFIS(O)	Aerodrome Flight Information Service (Officer)
agl	above ground level
AIC	Aeronautical Information Circular
amsl	above mean sea level
AOM	Aerodrome Operating Minima
APU	Auxiliary Power Unit
ASI	airspeed indicator
ATC(C)(O)	Air Traffic Control (Centre)(Officer)
ATIS	Automatic Terminal Information Service
ATPL	Airline Transport Pilot's Licence
BMAA	British Microlight Aircraft Association
BGA	British Gliding Association
BBAC	British Balloon and Airship Club
BHPA	British Hang Gliding & Paragliding Association
CAA	Civil Aviation Authority
CAVOK	Ceiling And Visibility OK (for VFR flight)
CAS	calibrated airspeed
cc	cubic centimetres
CG	Centre of Gravity
cm	centimetre(s)
CPL	Commercial Pilot's Licence
°C,F,M,T	Celsius, Fahrenheit, magnetic, true
CVR	Cockpit Voice Recorder
DFDR	Digital Flight Data Recorder
DME	Distance Measuring Equipment
EAS	equivalent airspeed
EASA	European Aviation Safety Agency
ECAM	Electronic Centralised Aircraft Monitoring
EGPWS	Enhanced GPWS
EGT	Exhaust Gas Temperature
EICAS	Engine Indication and Crew Alerting System
EPR	Engine Pressure Ratio
ETA	Estimated Time of Arrival
ETD	Estimated Time of Departure
FAA	Federal Aviation Administration (USA)
FIR	Flight Information Region
FL	Flight Level
ft	feet
ft/min	feet per minute
g	acceleration due to Earth's gravity
GPS	Global Positioning System
GPWS	Ground Proximity Warning System
hrs	hours (clock time as in 1200 hrs)
HP	high pressure
hPa	hectopascal (equivalent unit to mb)
IAS	indicated airspeed
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
IP	Intermediate Pressure
IR	Instrument Rating
ISA	International Standard Atmosphere
kg	kilogram(s)
KCAS	knots calibrated airspeed
KIAS	knots indicated airspeed
KTAS	knots true airspeed
km	kilometre(s)
kt	knot(s)
lb	pound(s)
LP	low pressure
LAA	Light Aircraft Association
LDA	Landing Distance Available
LPC	Licence Proficiency Check
m	metre(s)
mb	millibar(s)
MDA	Minimum Descent Altitude
METAR	a timed aerodrome meteorological report
min	minutes
mm	millimetre(s)
mph	miles per hour
MTWA	Maximum Total Weight Authorised
N	Newtons
N_R	Main rotor rotation speed (rotorcraft)
N_g	Gas generator rotation speed (rotorcraft)
N_1	engine fan or LP compressor speed
NDB	Non-Directional radio Beacon
nm	nautical mile(s)
NOTAM	Notice to Airmen
OAT	Outside Air Temperature
OPC	Operator Proficiency Check
PAPI	Precision Approach Path Indicator
PF	Pilot Flying
PIC	Pilot in Command
PM	Pilot Monitoring
POH	Pilot's Operating Handbook
PPL	Private Pilot's Licence
psi	pounds per square inch
QFE	altimeter pressure setting to indicate height above aerodrome
QNH	altimeter pressure setting to indicate elevation amsl
RA	Resolution Advisory
RFFS	Rescue and Fire Fighting Service
rpm	revolutions per minute
RTF	radiotelephony
RVR	Runway Visual Range
SAR	Search and Rescue
SB	Service Bulletin
SSR	Secondary Surveillance Radar
TA	Traffic Advisory
TAF	Terminal Aerodrome Forecast
TAS	true airspeed
TAWS	Terrain Awareness and Warning System
TCAS	Traffic Collision Avoidance System
TODA	Takeoff Distance Available
UA	Unmanned Aircraft
UAS	Unmanned Aircraft System
USG	US gallons
UTC	Co-ordinated Universal Time (GMT)
V	Volt(s)
V_1	Takeoff decision speed
V_2	Takeoff safety speed
V_R	Rotation speed
V_{REF}	Reference airspeed (approach)
V_{NE}	Never Exceed airspeed
VASI	Visual Approach Slope Indicator
VFR	Visual Flight Rules
VHF	Very High Frequency
VMC	Visual Meteorological Conditions
VOR	VHF Omnidirectional radio Range