Statens haverikommission
Swedish Accident Investigation Authority

Final report RL 2021:08e

Incident at Gällivare airport on 10 September 2020 involving ES-ACD of the model RJ Series 900, operated by Regional Jet OÜ.

File no. L-78/20

9 September 2021

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

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

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

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Content

General observations

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

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

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

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

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

The investigation

SHK was informed on 10 September 2020 that an incident involving one aircraft with the registration ES-ACD had occurred at Gällivare Airport, Norrbotten County, on the same day at 07.06 hrs.

The incident has been investigated by SHK represented by Mr Jonas Bäckstrand, Chairperson, Mr Tony Arvidsson, Investigator in Charge, and Mr Mats Trense, Operations Investigator.

The accredited representatives of the following countries from each authority for safety investigations have participated:

Canada, Ms Helen Tsai from the TSB (Transportation Safety Board of Canada).

United States, Mr Adam Huray from the NTSB (National Transportation Safety Board).

Netherlands, Ms Marieke van Hijum from the DSB (Dutch Safety Board).

Slovenia, Mr Urban Odlazek from AIIU (Slovenia Air, Maritime and Railway Accident and Incident Investigation Unit).

The type certificate holder MHI RJ Aviation ULC has participated as an adviser on behalf of Canada.

Collins Aerospace, Woodward MPC Inc. and BAE Systems has participated as advisors on behalf of the USA.

Mr David Waller has participated as an adviser for the EASA (European Union Aviation Safety Agency).

Mr Magnus Eneqvist and Mr Robert Jangfall have participated as advisers on behalf of the Swedish Transport Agency.

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

Investigation material

- Interviews have been conducted with the Commander and First Officer.
- Interviews have been conducted with the Air Traffic Service.
- Interviews have been conducted with the operator (Regional Jet OÜ).
- Interviews have been conducted with the operator's airworthiness organisation (CAMO[1]).
- Interviews have been conducted with the maintenance organisation (SAMCO).
- Data from the aircraft's CVR[2] and QAR[3]have been collected and analysed.
- Reports from the Commander and the airport.
- Meetings with the Type Certificate holder and accredited representatives.
- Technical examinations of the rudder control sensor (RVDT) and nose wheel steering electronic control unit (ECU).
- Examination of the aircraft.
- A film from the nose wheel steering test has been analysed.

A meeting with the interested parties was held on 1 March 2021. At the meeting SHK presented the facts established during the investigation, available at the time.

[1] CAMO – Continuing Airworthiness Management Organisation.
[2] CVR – Cockpit Voice Recorder.
[3] QAR – Quick Access Recorder.

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Aircraft:	
Registration, type	ES-ACD, CL-600 (Regional Jets RJ)
Model	CL-600-2D24 (RJ Series 900)
Class, Airworthiness	Normal, Certificate of Airworthiness and valid Airworthiness Review Certificate (ARC)[4]
Operator	Regional Jet OÜ
Time of occurrence	10 September 2020, 07.06 hrs in daylight Note: All times are given in Swedish day-light-saving time (UTC [5]+ 2 hours)
Place	Gällivare Airport, Norrbottens County, (position 67°08N 020°49E, 296 metres above mean sea level)
Type of flight	Commercial
Weather	According to Metar: wind 320 degrees 6 knots, CAVOK[6], temperature/dewpoint +02/+00°C, QNH[7] 992 hPa
Persons on board:	23
crew members including cabin crew	4
passengers	19
Injuries to persons	None
Damage to aircraft	Slightly damaged
Other damage	Runway light
Commander:	
Age, licence	47 years, ATPL[8](A)
Total flying hours	3 477 hours, of which 2 896 hours on type
Flying hours previous 90 days	24 hours, all on type
Number of landings previous 90 days	11
Co-pilot:	
Age, licence	26 years, CPL[9](A)
Total flying hours	869 hours, of which 708 hours on type
Flying hours previous 90 days	29 hours, all on type
Number of landings previous 90 days	21

[4] ARC – Airworthiness Review Certificate.
[5] UTC – Coordinated Universal Time.
[6] CAVOK – Ceiling And Visibility OK.
[7] QNH – Barometric pressure at mean sea level.
[8] ATPL – Airline Transport Pilot License.
[9] CPL – Commercial Pilot License.

SUMMARY

The incident occurred during a scheduled flight from Gällivare to Stockholm. At the time, the runway was dry and the weather conditions were good.

The airworthiness organisation had decided to replace the rudder control sensor (RVDT) despite the fact that there was no open remark in the technical logbook. The replacement was carried out by the contracted maintenance organisation.

The crew was aware that technical maintenance had been performed on the aircraft's nose wheel steering system the day before the flight.

After starting the engines, the commander taxied out the aircraft to take off from runway 30.

At take-off, the aircraft immediately turned left after the brakes were released and the aircraft began to roll. The commander tried to correct the course with the right rudder pedal to steer the aircraft to the right without stopping the aircraft's turning movement to the left. The commander decided to abort the take-off and the aircraft finally stopped with the nose wheel outside the runway.

Flight data showed that nose wheel steering with the rudder pedals steered the aircraft in the opposite direction from what was expected, which was also found in the technical examination.

An examination showed that the mechanical stop inside the rudder control sensor had been broken off. The examination also showed that if the mechanical stop is broken off, the missing spline on the sensor shaft can be installed two splines off from the rig position, without any systems warnings. The polarity of the electrical output signal will then be reversed, resulting in that steering with the rudder pedals steers the aircraft in the opposite direction.

The maintenance manual did not describe that a verification of the sensor function should be performed before installation. The maintenance manual also lacked a clear description how the sensor shaft should be aligned at installation.

After installation of the sensor, neither the steering direction nor the angle of the deflection was verified during a function test of the nose wheel steering with the rudder pedals.

The cause for the excursion was that the sensor for the nose wheel steering was incorrectly installed and that the prescribed functional test after installation of the sensor was not performed according to the maintenance manual. This led to that the nose wheel steering with the rudder pedals steered the aircraft in the opposite direction from the expected.

Contributing factors:

- The maintenance manual lacked sufficiently clear instructions to determine the correct function of the sensor before installation.
- The description in the maintenance manual on how to install the sensor did not include sufficiently detailed instructions on how the required sensor shaft alignment could be achieved in regards to the sensor design, function and the position.
- The lack of verification of the steering deflections with the rudder pedals during the function test indicates deficiencies in the maintenance organisation's and technician's routines regarding line maintenance planning and grouping of tasks for sign-off to prevent omissions during maintenance.
- The airworthiness organisation's participation in the safety management system lacked a focus on identifying risks between the maintenance organisation and the airworthiness organisation.

SAFETY RECOMMENDATIONS

None.

1. FACTUAL INFORMATION

1.1 History of the flight

1.1.1 Preconditions

The flight was a scheduled flight from Gällivare to Stockholm via Arvidsjaur. The crew had had two days off in Gällivare before the flight. The morning before the flight, the crew felt that they had plenty of time to make their preparations.

Technical maintenance was performed on the aircraft the day before the incident. The task was to replace a sensor in the nose wheel steering system.

It was daylight with good weather conditions. The wind was blowing lightly from northeast and the runway were dry.

1.1.2 History of the flight

After starting the engines, the crew performed actions according to the after-start checklist. The checklist ends with the rudder deflection being checked and the nose wheel steering being ARMED. The Commander taxied the aircraft out for take-off on runway 30. During the taxi, the Commander primarily used the nose wheel steering tiller to steer the aircraft. At the end of the runway, he turned around the aircraft in a narrow-left turn in order to be able to use the entire runway for take-off. He did not correct the aircrafts position to stand on the centreline of the runway. He therefore stopped a little to the left of the centreline with the cockpit positioned just before the runway marking 30.

The Commander in the left-hand pilot seat manoeuvred the aircraft. During take-off, the rudder pedals were normally used to steer the aircraft, he therefore had his left hand on the pilots control wheel, his right hand on the thrust levers and his feet on the rudder pedals.

During the initial take-off, the aircraft was stationary with the brakes applied. TOGA[10] was activated and the engines accelerated to a thrust of approximately 50 percent N1[11] by advancing both thrust levers. When both engines stabilized their engine speed, the Commander released the brakes and moved the thrust levers towards TOGA-position. The First Officer, who was the Pilot Monitoring, checked that the planned thrust was applied.

When the aircraft started the take-off roll it turned to the left. The Commander tried to correct the course with the right rudder pedal to steer the aircraft towards the centre of the runway. Despite this, the aircraft continued to turn left and he therefore applied more pedal deflection to the right rudder pedal without cancelling the left turn. The

[10] TOGA– Take-off/Go-around thrust mode.
[11] N1 – the speed of the low-pressure compressor or fan speed in a turbofan engine.

Commander decided to abort the take-off and pulled the thrust levers to idle and employed full brake. According to the Commander, he also tried to steer the aircraft using the nose wheel steering tiller without success.

After the take-off was aborted, the aircraft continued to turn left and finally stopped with the nose wheel off the edge of the runways hard surface.

Evacuation of the aircraft was not initiated because the Commander considered that there was no imminent danger.

The incident occurred at position 67°08N 020°49E, 296 metres above mean sea level.

1.2 Injuries to persons

	Crew members	Passengers	Total on-board	Others
Fatal	-	-	0	-
Serious	-	-	0	-
Minor	-	-	0	Not applicable
None	4	19	23	Not applicable
Total	4	19	23	-

1.3 Damage to aircraft

Slightly damaged.

1.4 Other damage

One runway light was damaged.

1.4.1 Environmental impact

None.

1.5 Personnel information

1.5.1 Qualifications and duty time of the pilots

Commander

The commander, was 47 years old and had an ATPL(A), valid flight operational eligibility and medical certificate. At the time the commander was PF[12].

[12] PF – Pilot Flying.

Flying hours				
Latest	24 hours	7 days	90 days	Total
All types	0	2	24	3 477
Actual type	0	2	24	2 896

Number of landings actual type previous 90 days:11.
Type rating concluded on 12 February 2020.
Latest PC[13] (proficiency check) conducted on 09 February 2020 on CL-65.

The co-pilot

The co-pilot, was 26 years old and had a CPL(A), valid flight operational eligibility and medical certificate. At the time the co-pilot was PM[14].

Flying hours				
Latest	24 hours	7 days	90 days	Total
All types	0	2	29	869
Actual type	0	2	29	708

Number of landings actual type previous 90 days: 21.
Type rating concluded on 8 March 2019.
Latest PC conducted on 31 July 2020 on CL-65.

1.5.2 Cabin crew

The cabin crew consisted of two persons, both stationed in Gällivare.

1.5.3 Other personnel

The technician that worked for the maintenance organisation was at the time stationed in Gällivare and had a valid Part-66 Aircraft Maintenance License. He had a valid rating for Bombardier CL-600-2C10/-2D15/-2D24/-2E25, B1 Category.

According to the organisations training records he had performed all mandatory training. The initial training (SAMCO AMO[15] procedures) was performed 7 February 2019. According to SAMCO’s procedures, the technician at the line station also had a planning function. There was no specific training for this.

[13] PC – Proficiency Check.
[14] PM – Pilot Monitoring.
[15] AMO – Approved Maintenance Organisation.

1.6 Aircraft information

The aircraft of the model CL-600-2D24 (RJ Series 900) is a twin-engine low-wing regional jet aircraft. The aircraft is intended for transport over short and medium distances. The aircraft is 36.24 metres long, has a span of 24.85 metres and is equipped with a pressure cabin. The aircraft has two turbofan engines manufactured by General Electric Company.

Figure 1. The aircraft. Photo: Max Litvinko.

1.6.1 Airplane

TC-holder	MHI RJ AVIATION ULC
Model	CL-600-2D24 (RJ Series 900)
Serial number	15276
Year of manufacture	2011
Gross mass, kg	Max start mass 36 995, current 28 025
Centre of gravity	Within limits. CG/Index 23.1
Total flying time, hours	21 789
Engine	
TC-holder	GENERAL ELECTRIC COMPANY
Type	CF34-8C5
Number of engines	2
Deferred remarks	None

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

1.6.2 Nosewheel steering

The nosewheel steering system provides directional control of the airplane on the ground for taxi, take-off and landing operations.

The nosewheel steering system is controlled by a steering Electronic Control Unit (ECU) and powered by hydraulic system no. 3. The nosewheel steering arming switch is located on the pilot left side panel. Selecting the switch to the ARMED position arms the nose wheel steering system (NWS). The ECU controls the nosewheel position based on inputs from either the nose wheel steering tiller on the left-hand pilot side console, or the rudder pedals. The nose wheel steering tiller turns the nosewheel up to 80 degrees from either side of centre, and is intended for low speed taxiing. Steering with the rudder pedals is limited to 8 degrees from either side of centre and is intended for high speed taxi, take-off and landing rolls.

After take-off, the steering control unit generates a straight ahead command, which centers the nose wheel prior to landing gear retraction. A centering cam on the nosewheel strut maintains the nosewheel centre position when the strut is fully extended.

Powered steering using the nose wheel steering tiller is available when the steering switch on the pilot left-hand side panel is ARMED and a nose weight-on-wheels signal is present.

If a failure is detected by the steering ECU or hydraulic system no. 3 is lost, the system reverts to shimmy-damping mode which allows free castoring of the nosewheel. The pilot then maintains ground directional control through differential braking and differential thrust.

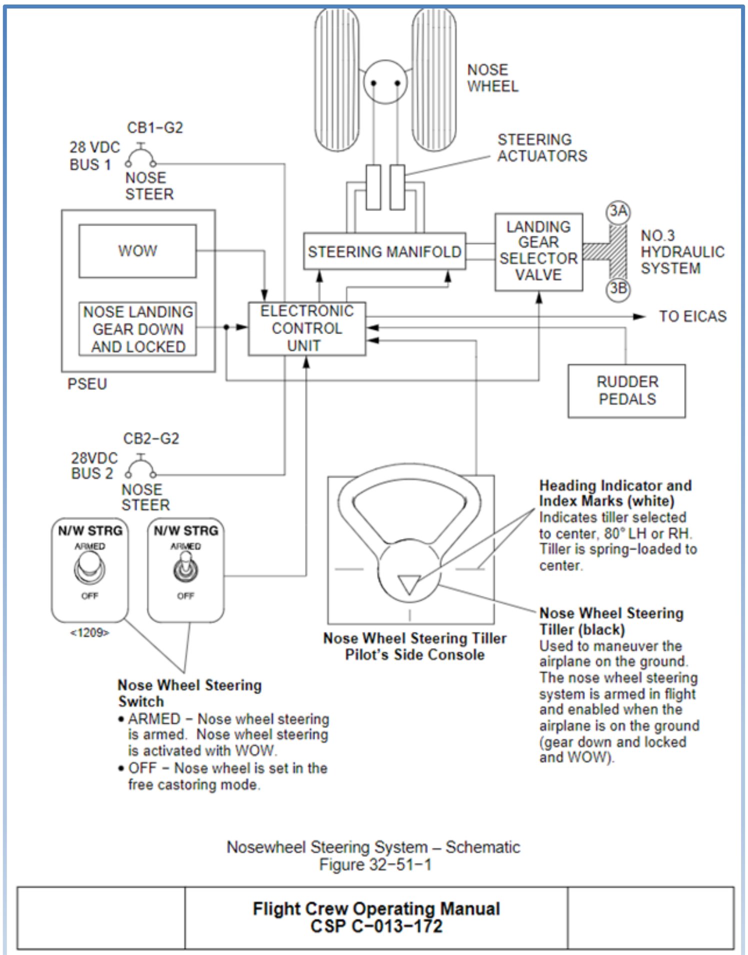


Figure 2. Nose Wheel Steering System. Image: CRJ-900 FCOM[16].

[16] FCOM – Flight Crew Operating Manual.

1.6.3 Rudder control (RVDT) assembly

The rudder control sensor (RVDT) is a self-contained bolt-on assembly, located on the right rudder front pivot assembly. Movement of the rudder pedals rotates the sensor and provides input signals to the ECU proportional to the rudder pedal position. It also provides rudder pedal position information to the flight data recorder.

Figure 3. The picture on the left shows were the sensor is installed in the aircraft, in front of the rudder pedals on the right-hand side, see arrow. The picture on the right shows the sensor installed in the aircraft with panels removed.

1.6.4 Rudder control sensor (RVDT), electrical and mechanical characteristics

The sensor has a flexible spline shaft with a missing spline. The radial separation between the teeth provides eight theoretical different possibilities to install the shaft in the pivot assembly. This means a separation of 45 degrees for each position (see Figure 4).

Inside the unit there are two mechanical stops that limit the stroke to +/-55 degrees from zero, 110 degrees in total. The mechanical rig position is when the missing spline on the shaft of the sensor aligns with the red dot on the underside of the sensor, which is also the electrical zero (see Figure 4 and 5).

When the sensor is not mounted, its shaft is driven clockwise against the mechanical stop +55 degrees, by a return spring. In this position, the electrical output is +35 degrees.

The calibrated range of the sensor is +/-40 degrees from zero and the rudder pedal range is +/-24 degrees.

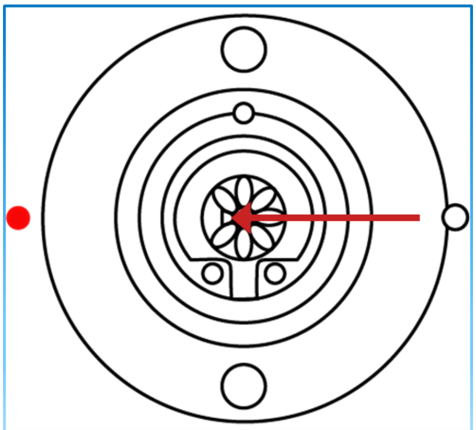


Figure 4. A schematic view of the sensor's splined shaft. The red arrow marks the missing spline. The sensor is in the rig position. The missing spline and the red dot are aligned.

Correct Rig Position

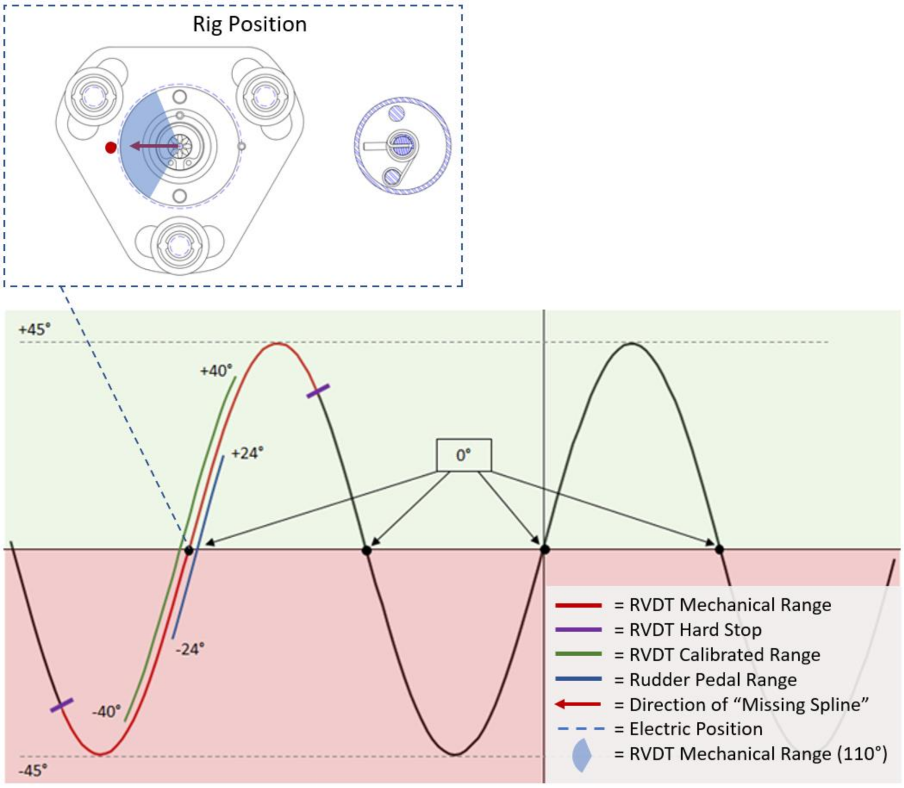


Figure 5. Electrical and mechanical characteristics with rudder control sensor correctly installed. Clockwise rotation of the shaft results in positive electrical output. Illustrated in the figure are four electrical zeros (four quadrants). The figure illustrates the sensor installed in the correct mechanical rig position and at the correct electrical zero point.

Incorrect Rig Positions

It is possible to install the sensor in the wrong position. Two scenarios are described: One with the shaft installed one tooth off the rigging position, and the other two teeth off from the rigging position. When the body of the sensor is correctly installed in the aircraft, the red dot points forward in the direction of flight (see Figure 6).

If the missing spline is installed one tooth off (45 degrees) in the clockwise direction seen from below the sensor, the stroke to the mechanical stop will be reduced from +55 degrees to +10 degrees. If its installed in this position a right rudder deflection can easily brake the clockwise hard stop. At the same time the stroke to the counter clockwise hard stop has increased to 100 degrees. The electrical position will be +45 degrees and in this scenario it's not possible to rig the sensor and get an approved result with the aircraft's maintenance diagnostic computer (see Figure 6, One Tooth Incorrect Install).

If the clockwise hard stop is broken the missing spline can be installed two teeth off (90 degrees) from the rig position. In this scenario the broken hard stop allows the shaft to rotate in to the next quadrant's electrical zero. In this position it is possible to rig the sensor and get an approved result with the aircraft's maintenance diagnostic computer. The polarity of the electrical output signal will be reversed, compared with the sensor output signal when the sensor is correctly installed (see Figure 6, Two Tooth Incorrect Install).

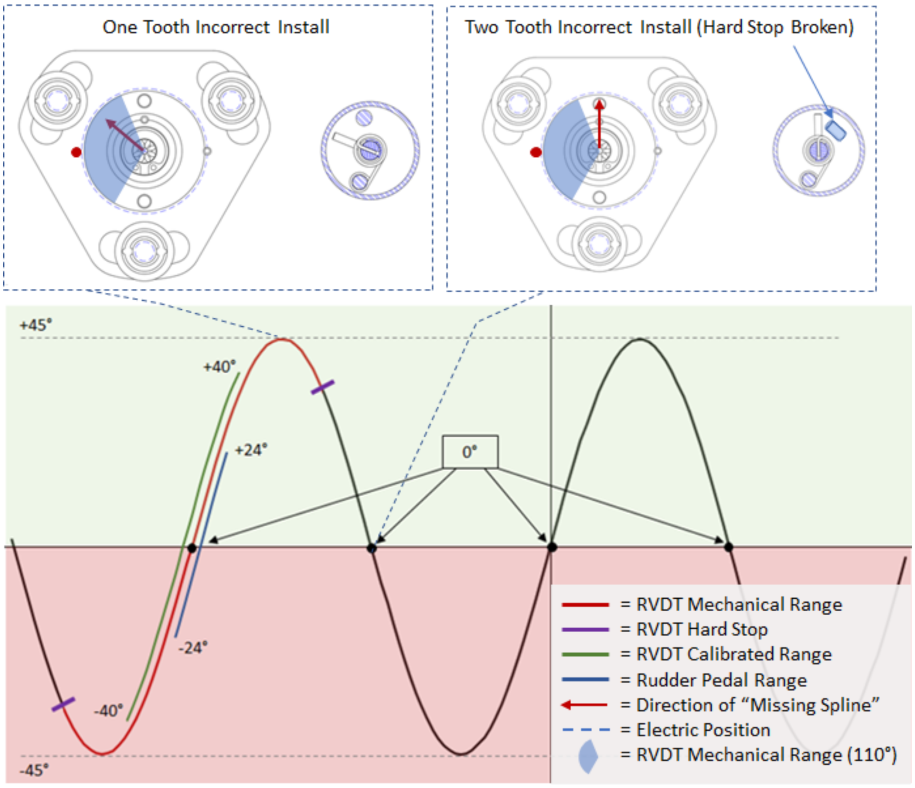


Figure 6. Electrical and mechanical characteristics if the missing spline on the sensor shaft is installed one or two teeth off from the rig position, clockwise seen from below the sensor.

1.6.5 *Fault history, nosewheel steering*

In this section, only relevant parts and main events will be described, even though there have been more communications between the airworthiness organisation of the operator (CAMO) and the type certificate holder.

Earlier in the summer, a number of remarks had been written in the aircraft's technical logbook that were related to the nose wheel steering. The remarks described a problem where the nose wheel was not centered after the aircraft had been parked for a couple of hours, without electric power or hydraulic power.

The operator's airworthiness organisation (CAMO) contacted the type certificate holder for assistance in troubleshooting. The troubleshooting resulted in a number of measures and the replacement of a number of different components in the nose wheel steering system, including a steering actuator and a steering manifold.

On 6 September 2020 in Gällivare, a pilot during a pre-flight check observed that the nose wheel was not centered, which resulted in a remark in the aircraft technical logbook.

The technician who was on duty at the station in Gällivare started the troubleshooting. The aircraft's maintenance computer presented two fault codes related to the rudder control sensor. Further investigation showed that the position of the sensor was close to the limit of the approved adjustment range. The sensor was adjusted using the aircraft maintenance computer. The adjustment of the sensor was documented in the aircraft technical logbook on 6 September 2020 and the remark was closed.

The technician wrote an email to the operator's airworthiness organisation in which he described the remark, the troubleshooting and actions taken. The operator's airworthiness organisation contacted the type certificate holder to describe the that the nose wheel was not centred after the aircraft had been parked for a while. In addition, they described that the rudder control sensor was close to the approved limit and had been adjusted.

Answer from the type certificate holder, 6 September 2020:

"*Based on this new information, our current recommendation would be to replace rudder control sensor if the problem persists.*"

"However, this does not explain why the steering continues to move (left or right) after electric power and hydraulic power have been switched off."

On 7 September 2020 a pilot was requested by the airworthiness organisation to perform a taxi test. The pilot experienced that the aircraft steered to the left when taxiing without correction with the nose wheel steering tiller or rudder pedals. A safety report was created by the pilot but no remark was entered in the aircraft's technical logbook.

The operator's airworthiness organisation decided to replace the sensor. The Maintenance Coordination Center (MCC) issued a workorder to replace the rudder control sensor (RVDT). The workorder was sent to the station in Gällivare in the afternoon 8 September 2020. The same evening the sensor arrived to Gällivare. The sensor that was to be installed in ES-ACD was removed from another aircraft (ES-ACB), parked at Arlanda.

1.6.6 Replacement of the Rudder Control Sensor (RVDT)

The replacement of the sensor was performed the day before the incident, on 9 September 2020. At the time, there was no open or deferred remark in the aircraft's technical logbook regarding the nose wheel steering. The airworthiness organisation regarded the work as unplanned maintenance. During the interviews, the technician who was alone on duty at the line station stated that there was no time pressure because the replacement of the sensor was the only job he had planned to perform during that day. He also stated that this was the first time he performed a replacement of the rudder control sensor.

The technician printed the instructions for removal and installation of the sensor from the aircraft maintenance manual. Work began to remove the sensor. The maintenance certificates for the sensor were reviewed and accepted, and the installation of the new sensor was initiated.

According to the technician, the sensor went in easily when the shaft was pushed down into the pivot assy. The sensor was rigged using the aircraft's computer for maintenance within approved tolerance and result, which meant that he did not need to remove the sensor again (see Figure 7).

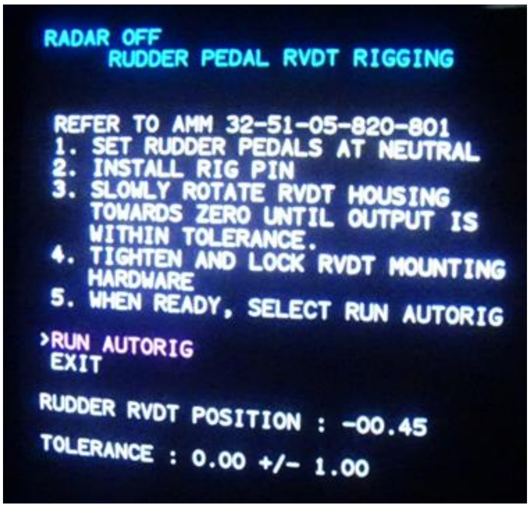


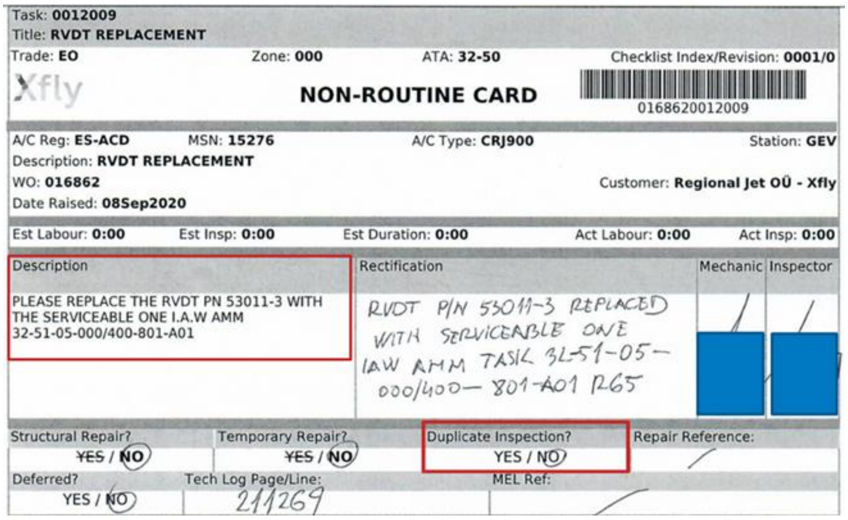
Figure 7. Picture from the rigging page for the rudder control sensor taken by SHK during the technical examination. The approved range is 0.00 degrees with a tolerance of +/-1.0 degrees.

The test of the nose wheel steering after the replacement of the sensor, was, according to the technician, performed by him sitting in the cockpit turning the nose wheel steering tiller. To see the steering deflections during the actual test, he had placed his phone outside the aircraft to film this. After the test, he watched the recorded film and noticed that the steering linkage was moving in both directions.

The test also included checking the correct steering range by using the rudder pedals. The technician has stated that the aircraft moved when he pressed the rudder pedals and he assumed that the steering worked. The steering deflections with the rudder pedals were not filmed.

Although the installation was not classified as a critical maintenance task the technician took a break, and then re-checked the work he had performed, a so-called re-inspection. On the work order from the operator's CAMO, he signed that work had been performed in both the mechanic's and the inspector's box.

In the aircraft's technical log, it was documented that the installation was carried out in accordance with reference AMM 32-51-05-000/400-801-A01, revision 65.


Task: 0012009
Title: RVDT REPLACEMENT
Trade: EO Zone: 000 ATA: 32-50 Checklist Index/Revision: 0001/0
Xfly NON-ROUTINE CARD 0168620012009
A/C Reg: ES-ACD MSN: 15276 A/C Type: CRJ900 Station: GEV
Description: RVDT REPLACEMENT
WO: 016862 Customer: Regional Jet OÜ - Xfly
Date Raised: 08Sep2020
Est Labour: 0:00 Est Insp: 0:00 Est Duration: 0:00 Act Labour: 0:00 Act Insp: 0:00

Description	Rectification	Mechanic	Inspector
PLEASE REPLACE THE RVDT PN 53011-3 WITH THE SERVICEABLE ONE I.A.W AMM 32-51-05-000/400-801-A01	RVDT P/N 53011-3 REPLACED WITH SERVICEABLE ONE IAW AMM TASK 32-51-05-000/400-801-A01 R65		

Structural Repair? YES / NO Temporary Repair? YES / NO Duplicate Inspection? YES / NO Repair Reference:
Deferred? YES / NO Tech Log Page/Line: 211269 MEL Ref:

Figure 8. Work Order from the sensor replacement. Image: Regional Jet OÜ.

1.6.7 *AMM*[17]

The maintenance manual describes the removal and installing task of the rudder control sensor (RVDT). The sensor is installed on the right rudder front pivot assembly located under the floor in the cockpit.

To get access to the sensor, panels need to be removed. The manual described only one panel, which provided access for installation of the rigging pin in the pivot assembly.

[17] AMM – Aircraft Maintenance Manual.

The installation chapter described a number of cautions and conditions that should be met before the sensor was installed on the pivot assembly.

The conditions that should be met were as follows:

- The missing spline on the shaft of the sensor and the missing spline on the rudder pedal pivot assembly must be aligned.
- The missing spline on the sensor should align with the red dot and point forward.
- The electrical receptacle on the sensor points inboard.

The cautions also described that if you do not follow the above conditions, the sensor will be damaged and may cause the aircraft to steer in the opposite direction during operation.

It is noted in the installation section that it is possible to install the sensor in the pivot assembly even if the missing splines are not aligned.

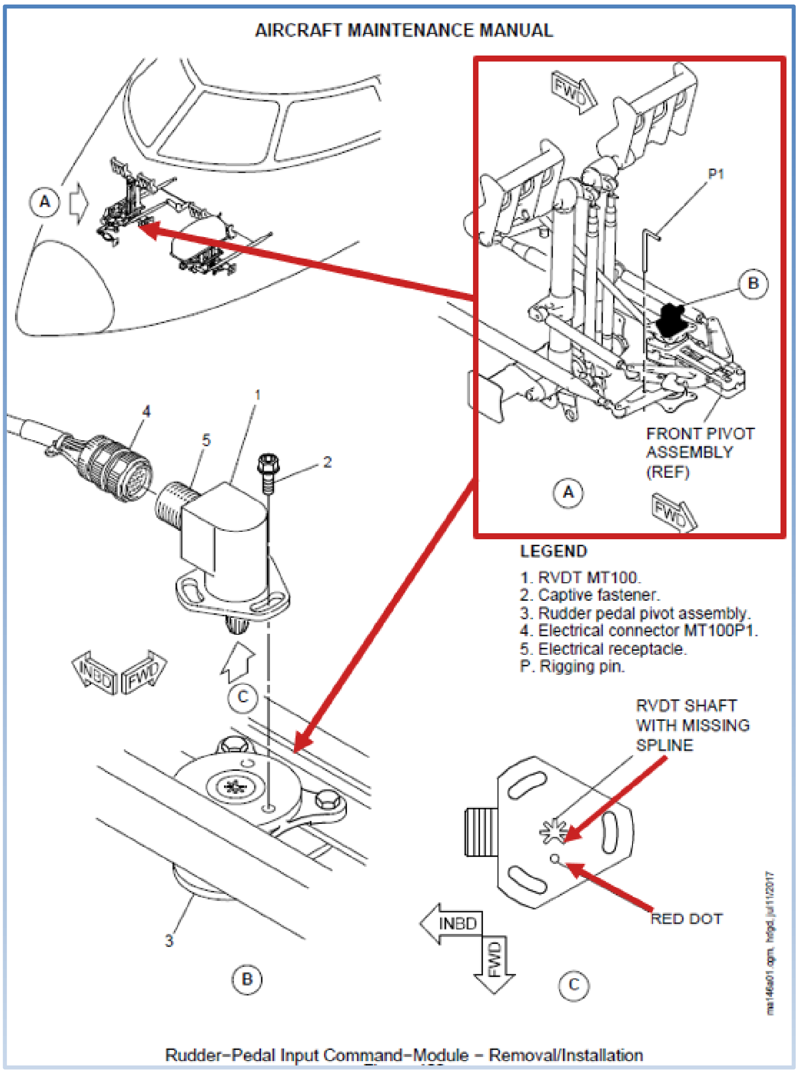


Figure 9. A figure from the installation chapter in the AMM. Image: AMM 32−51−05−400−801.

Figure 10. The photo to the left shows the pivot assembly with the sensor removed. The photo in the middle shows the depth to the splines from the flange on the pivot assembly. The right image shows the sensor partially installed. If the sensor is raised a little more from this position, the splined shaft will disengage from the pivot assy.

1.7 Meteorological information

According to Metar: Wind 320 degrees 6 knots, CAVOK, temperature/dewpoint +02/+00°C, QNH 992 hPa.

1.8 Aids to navigation

Not relevant.

1.9 Communications

Not relevant.

1.10 Aerodrome information

Gällivare Airport had status according to AIP[18] Sweden. The runway was 1 784 metres long, 45 metres wide and dry at the time.

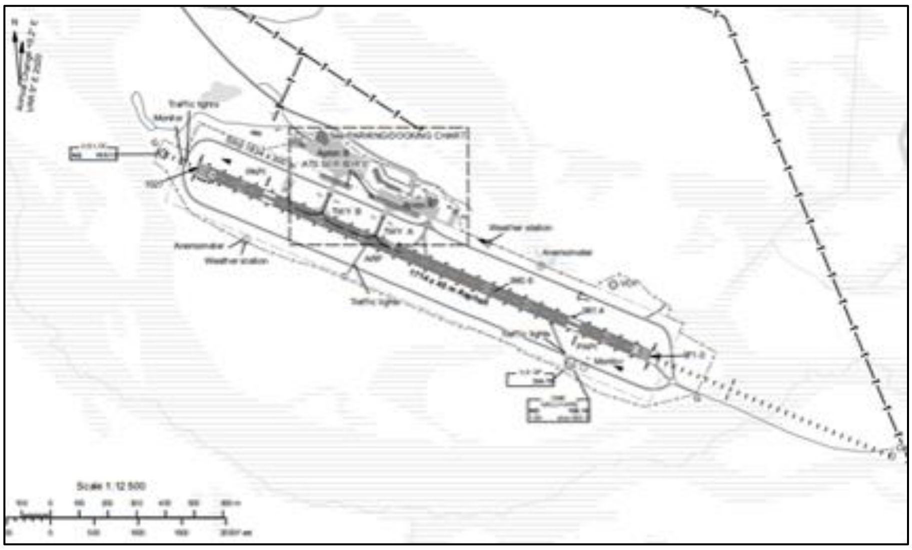


Figure 11. Gällivare Airport. Image: AIP Sweden.

[18] AIP – Aeronautical Information Publication.

Figure 12. Photo taken over the runway and the airfield in the take-off direction. Tire tracks after the incident can be seen after the runway marking 30.

1.11 Flight recorders

The aircraft was equipped with two recorders for flight data and one recorder for audio.

1.11.1 Flight Recorders

Installed on board was a DFDR[19] of the model FA2100 and a QAR[20] from L3 that register and records the same parameters. QAR data is used to present flight data (see Figure 13).

[19] DFDR – Digital Flight Data Recorder.
[20] QAR – Quick Access Recorder.

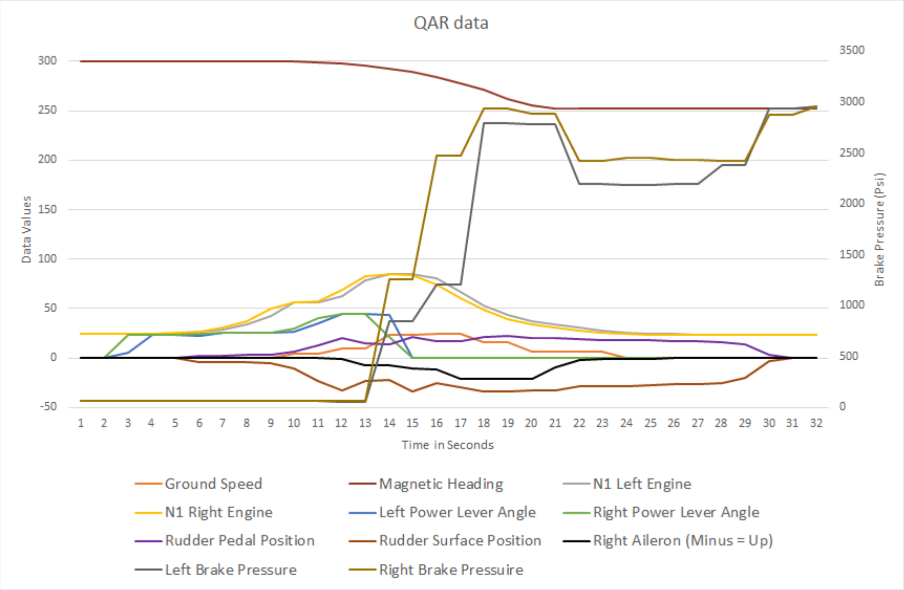


Figure 13. QAR data. Relevant parameters for the incident.

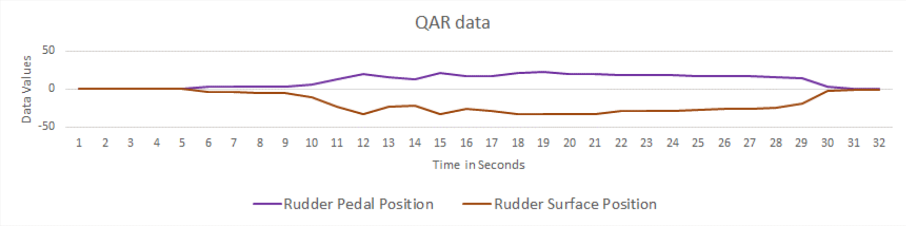


Figure 14. QAR data. The brown line illustrates the Rudder Surface Position and the purple line illustrates the Rudder Pedal Position.

The conversion document CRJ700/705/900/1000-31-008 Rev I describes the interpretations of the data stored in the DFDR and QAR. The parameters Rudder Surface Position and Rudder Pedal Position have the same sign direction. When pressing right rudder pedal both parameters shall have a negative value. In figure 14 the Rudder Pedal Position has positive value.

The nose wheel steering tiller deflection is not recorded in the flight data.

1.11.2 Cockpit Voice Recorder (CVR[21])

The audio files from CVR were downloaded by SAAB in Linköping and resulted in four audio files with 2 hours, 4 minutes and 14 seconds of recording. The recording quality was noisy, but audible. The communication was in English and corresponds to what is described in the history of flight in section 1.1.

[21] CVR – Cockpit Voice Recorder.

1.11.3 Animation

TSB Canada has produced an animation of the course of events. The aircraft's recorded data regarding the parameters longitude and latitude parameters were of poor quality. Some calculations have therefore been performed by TSB Canada, using recorded acceleration to create the path of the aircraft on the ground. Below are three images from the animation, taken at the same time (see Figures 15 to 17).

Figure 15. The aircrafts path on the ground. Image: TSB Canada.

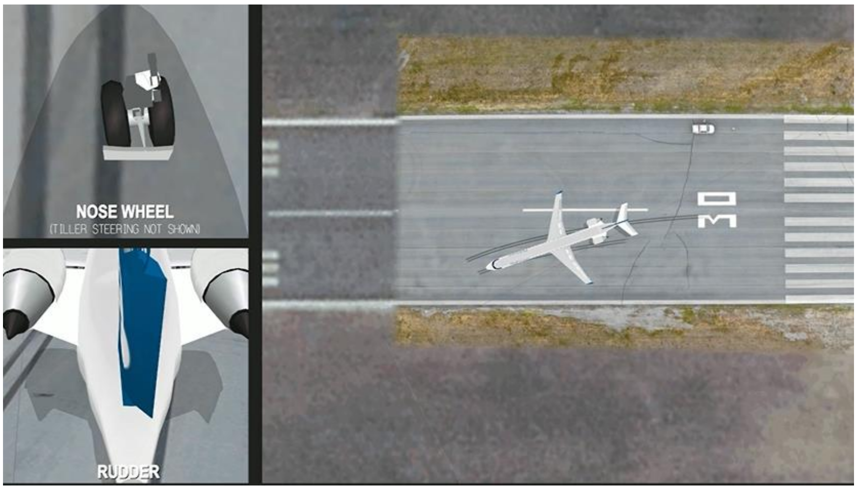


Figure 16. The nose wheels are turning to the left and the Rudder Surface Position is to the right. Image: TSB Canada.

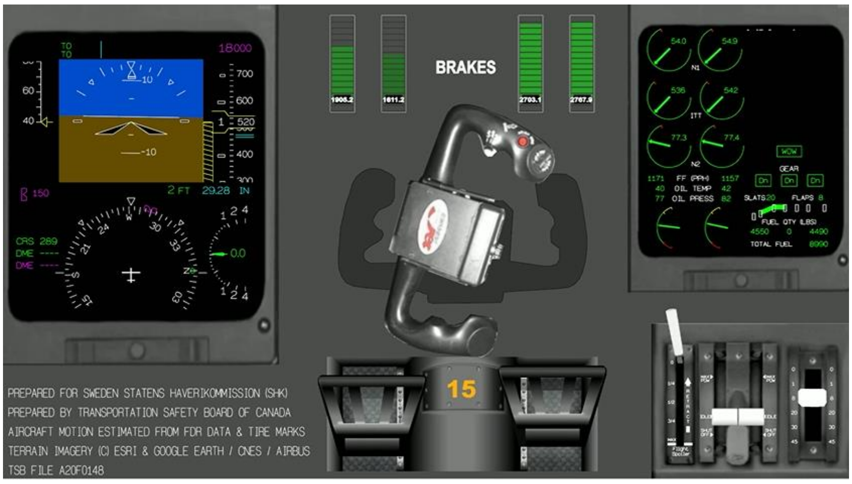


Figure 17. Right rudder pedal depressed, pilots control wheel turned fully to the right and right-hand brake applied more than the left. The flight instruments do not correspond to the aircraft's installed instruments. Image: TSB Canada.

1.12 Site of occurrence

The aircraft stopped on the left-hand side of runway 30, 120 metres from the start of the runway.

Figure 18. The aircraft's final position after the incident. After the runway marking 30, the black tire tracks are visible from the main wheels. Photo: The Rescue service Gällivare Airport.

1.12.1 The aircraft after the incident

Figure 19. The aircraft came to a full stop with the nosewheel off the left side of the runway hard surface. Photo: The Rescue service Gällivare Airport.

The rim on one of the nose wheels was damaged.

1.12.2 Technical examination of the aircraft

SHK carried out an investigation of the aircraft on 14 and 15 September 2020 in the hangar at the airport, where the aircraft had been towed after the incident.

During the visual inspection, it was found that the position of the rudder control sensor (RVDT) corresponded to the installation description in the Aircrafts Maintenance Manual (see Figure 20). The rigging page for the sensor in the maintenance computer, showed -00.43 degrees with the rudder pedals in neutral position (see Figure 21). In the maintenance computer there were no fault codes which were related to the nose wheel steering.

A functional test of the nose wheel steering was performed with the rudder pedals. The test resulted in the steering being in the opposite direction from the expected. The same functional test was performed with the nose wheel steering tiller, without remarks. To verify this, a taxi-test was performed with the aircraft where the opposite direction of control with the rudder pedals was confirmed. The test also showed that the rudder pedal steering angle could be overcome by turning the nose wheel steering tiller in the opposite direction. This is in accordance with the design of the system.

Figure 20. The sensor (RVDT) installed in the aircraft according to the installation description at the technical examination.

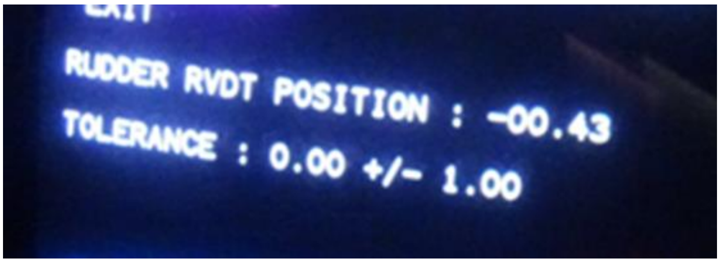


Figure 21. The page for sensor (RVDT) rigging, in the maintenance computer. -00.43 degrees with the rudder pedals in neutral position.

The sensor that was mounted at the incident was removed for further investigation. When compared to a sensor previously installed, it was found that there were differences between them.

The sensor that was installed at the time of the incident, serial number A0648, had a larger range of motion than the sensor that had previously been installed, serial number A0681 (see Figure 22).

When the shaft was manually turned counter clockwise and clockwise on the sensor with serial number A0648, it felt as if there was an obstruction when it passed the red dot, where it sometimes also got stuck (see the picture to the right in Figure 22).

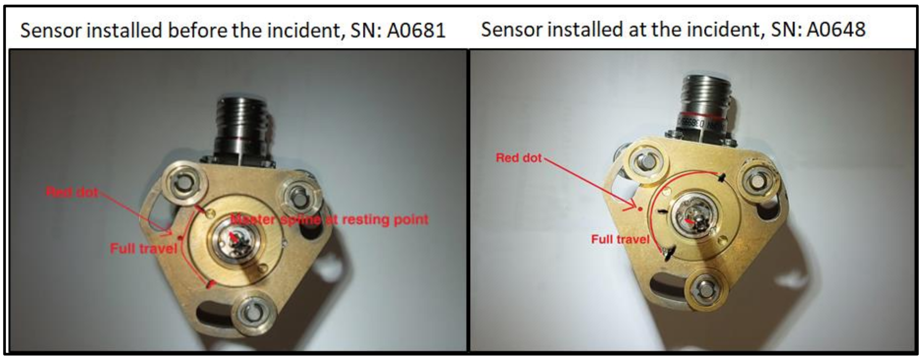


Figure 22. Pictures of the sensors (RVDT) that were compared. Left picture: The range of motion is marked with a red line, the flex shaft with missing spline is spring-loaded against the mechanical stop, +55 degrees (clockwise seen from this view). Right picture: The range of motion, marked with a red line, is longer compared to the left picture. The missing spline on the flex shaft is stuck at the red dot.

The sensors were sent to the manufacturer for testing and troubleshooting, see section 1.16.2. Nose wheel steering electronic control unit (ECU) was sent to the manufacturer for memory read out and functional test, see section 1.16.1.

A test installation of the previously mounted sensor showed that it was easy to install the sensor shaft missing spline one tooth off from the rig position. With the sensor shaft in this position, it was not possible to adjust the sensor and get an approved result with the aircraft's maintenance diagnostic computer.

During the examination, no other faults were discovered on the aircraft that could have caused the opposite steering direction of the nose wheels.

Aileron Test

The aim of the test was to clarify if the aileron system returns to neutral when the control wheel is released from a full right aileron input. The test demonstrated that the control column and the ailerons returned to neutral position.

1.13 Medical and pathological information

There is nothing to indicate that the mental and physical condition of the pilot was impaired before or during the incident.

1.14 Fire

No fire.

1.15 Survival aspects

1.15.1 Rescue operation

At the time of the incident, there were personnel from the airport's rescue service who saw the event and initiated the rescue operation.

The rescue leader, who was first on site, could state that there was no leakage, fire or visible damage to the aircraft and no immediate danger to the persons on board. A decision was made not to alert SOS Alarm.

In order to be able to communicate with the commander on board the aircraft, contact was made with personnel in the air traffic control tower because the rescue service's own aircraft radio was without power. Via the air traffic controller, the commander could be contacted for evacuation of the passengers and further transport to the station building.

The ELT[22] manufactured by Artex C406-2, PN: 453-5000 was not activated during the incident.

1.15.2 Position of crew and passengers and the use of seat belts

Everyone in the crew was strapped in at the incident.

1.16 Tests and research

1.16.1 Memory readout and functional test of nose wheel steering ECU[23]

The examination and testing of the unit with SN: 00957 were conducted on 21 October 2020 at the BAE Systems Service Center. The examinations were carried out by personnel from BAE Systems without supervision by SHK or NTSB.

A visual inspection was performed and no signs of damage or other anomalies were observed. The connector pins were examined without remarks. Data from the memory was downloaded without incident and a functional test was performed where the unit passed all tests.

All fault codes were downloaded. The relevant fault codes for the event will be described below.

[22] ELT – Emergency Locator Transmitter.
[23] ECU – Electronic Control Unit.

On the 6 September 2020, the same day as an adjustment of the rudder control sensor (RVDT) was performed, the following relevant fault codes were logged.

- Fault code 0021, RIGGING_RCM_FAIL, the position of the rudder control sensor (RVDT) outside approved limits.
- Fault code 0022, RIGGING_FBK_FAIL, nose wheel position (LVDT[24]) is not within limit.

The fault codes indicate that the steering electronic control unit (ECU) has detected that the position for the rudder pedals and the nose wheel position (LVDT) were outside the approved limits. Both faults correlate with the adjustment of the rudder control sensor RVDT.

On the 9 September 2020, the same day as the installation of the new sensor (RVDT) was performed, the following relevant fault codes were logged.

- Sep 09, 00:00:00 Fault Code 000A - RCM_REAS_FAIL
- [DATE/TIME - INVALID!] Fault Code 000A - RCM_REAS_FAIL

000A	RCM_REAS_FAIL	CMD	RCM Reasonableness Monitor	5.4.2	The RCM Reasonableness monitor shall {SRD-01930} declare RCM Reasonableness Monitor failure if the absolute value of the Rudder Pedal Angle is greater than 32° for 100 ms or longer.

Figure 23. Explanation of fault code 000A, from BAE Systems manual.

The fault code 000A - RCM_REAS_FAIL was logged two times. The first time with date but no time and the second with both date and time invalid.

The purpose of the Reasonableness Monitor (RCM) is to detect if the input signal from the rudder control sensor (RVDT) exceeds ± 32 degrees of shaft rotation for 100 ms or longer, which generates the fault code 000A - RCM_REAS_FAIL. As the name implies, this is a check of reasonableness with respect to expected commands from the rudder control sensor

There is no monitoring to detect rigging polarity of the sensor (RVDT). The ECU cannot determine the correct polarity due to the sensor having a sinusoidal output with multiple electrical zero positions.

[24] LVDT – Linear Variable Differential Transformer.

1.16.2 *Examination of rudder control sensor (RVDT), S/N 0648*

The examination of the sensor was performed by Woodward MPC, Inc. Due to the situation with Covid-19, SHK followed the examination via a video conference system.

The examination included visual inspection, x-ray, production testing and disassembly of the sensor.

At the external visual inspection, it was noted that when the sensor shaft was rotated counter clockwise and back clockwise, the expected clockwise rotation was not smooth and it felt as if there was an obstruction that must be overcomed before the shaft came to a stop.

During the production test, the sensor did not meet the accuracy requirement at 40 degrees clockwise position. A deviation of -.0033 volt was measured. The requirement for the test where the shaft will spring back against the mechanical stop was also not met.

The sensor was X-rayed and it was found that the unit had internal damage. The mechanical stop number two had dislodged from its original position (see Figure 24).

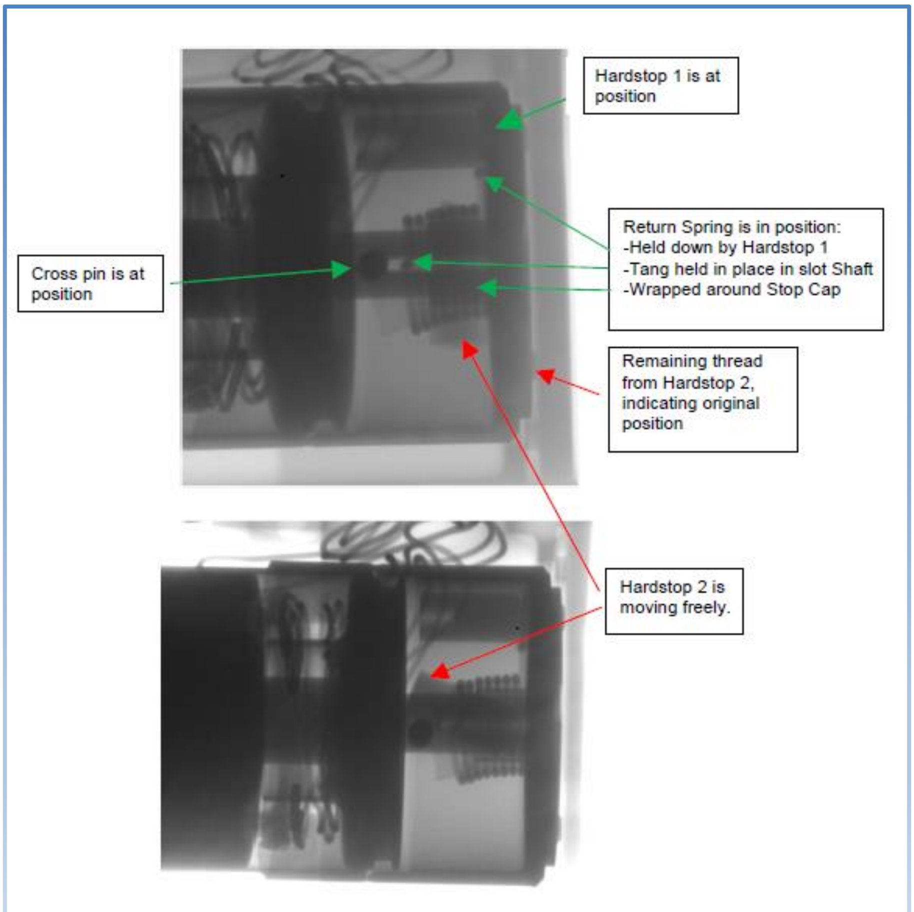


Figure 24. X-ray's from the examination. The lower image with a darker contrast.

Based on the result of the X-ray and the production test, the sensor was disassembled into sub-components for further examination (see Figures 25 to 27).

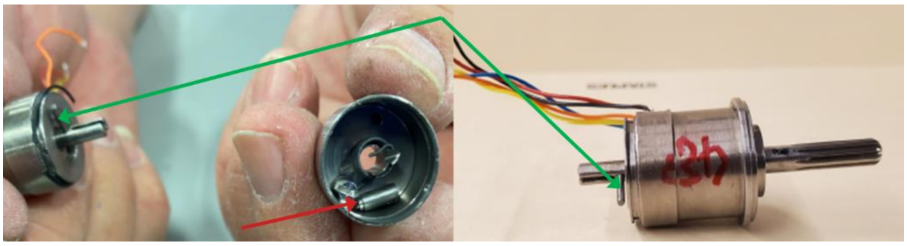


Figure 25. The sensor after disassembly. The green arrows show the cross pin on the shaft. The red arrow shows the hard stop that is loose in the stop cap assembly.

The following damage could be found in the stop cap, which was dismantled from the sensor unit. Mechanical stop number two had been broken off, the end of the return spring was bent and the stop cap was damaged at the end of the return spring (see Figures 26 and 27).

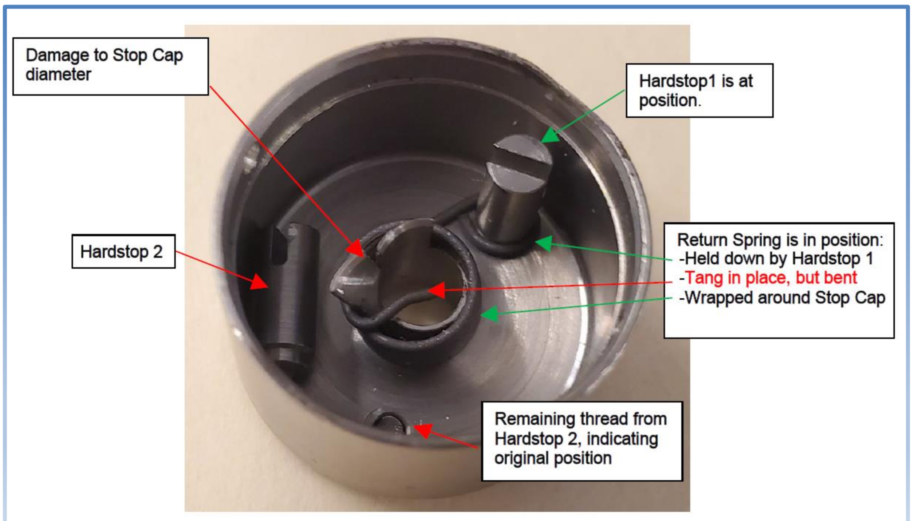


Figure 26. Close-up of the disassembled stop cap assembly.

Figure 27. Hard stop that had been broken off and was loose in the stop cap assembly. The red arrow shows the fracture location.

The force that is required to break the hard stop is 15.9 lbf (pound-force) according to Woodward MPC Inc.

The examination showed that the deviation of the output signal is due to the mechanical stop number two had been detached from its original position. Due to the fact that the mechanical stop had been broken off, the sensor shaft could rotate outside the intended working range.

Examination of rudder control sensor (RVDT), S/N 0681

The examination of the sensor was performed by Woodward MPC, Inc with participation of SHK via video conference system.

The examination included visual inspection, x-ray, production testing and disassembly of the sensor.

During the examination, no faults were found on the sensor that had been installed before the incident.

1.17 Organisational and management information

1.17.1 The operator, Regional Jet OÜ

Regional Jet OÜ is an aviation company engaged in commercial air transport (CAT) (passengers and cargo). The headquarter is located in Tallinn, Estonia. The operator had a valid AOC permit No.EE.020, issued by the Civil Aviation Administration, Estonia.

Regional Jet OÜ operates aircraft of the models, CRJ 700/900 and ATR 72-600-series.

Regional Jet OÜ had a Continuing Airworthiness Management Organisation (CAMO) to comply with the requirements of EASA Part-M. The organisation had an approved CRJ900 Aircraft Maintenance Program.

Regional Jet OÜ, under the brand Xfly, had contracted the maintenance organisation SAMCO Aircraft Maintenance B.V. (CRJ700/900 Line and Base maintenance). The contract was initially signed 24 of June 2016 and were last revised on 14 August 2020.

1.17.2 Safety Management System, Regional Jet OÜ

Regional Jet had a management system for compliance (CMS) and a safety management system (SMS). The system was described in the document Management System Manual (MSM). The manual combined safety management for the operator, an approved training organisation, an airworthiness organisation and a maintenance organisation in an integrated safety management system. MSM was the basic tool for communicating safety and compliance to all personnel. The MSM also covered the requirements for a management system under the Continuous Airworthiness Regulation (Del-CAMO).

A risk management process was described in the MSM (see Figure 28). The overarching goal for the risk management was to ensure a level of risk in accordance with ALARP[25] .

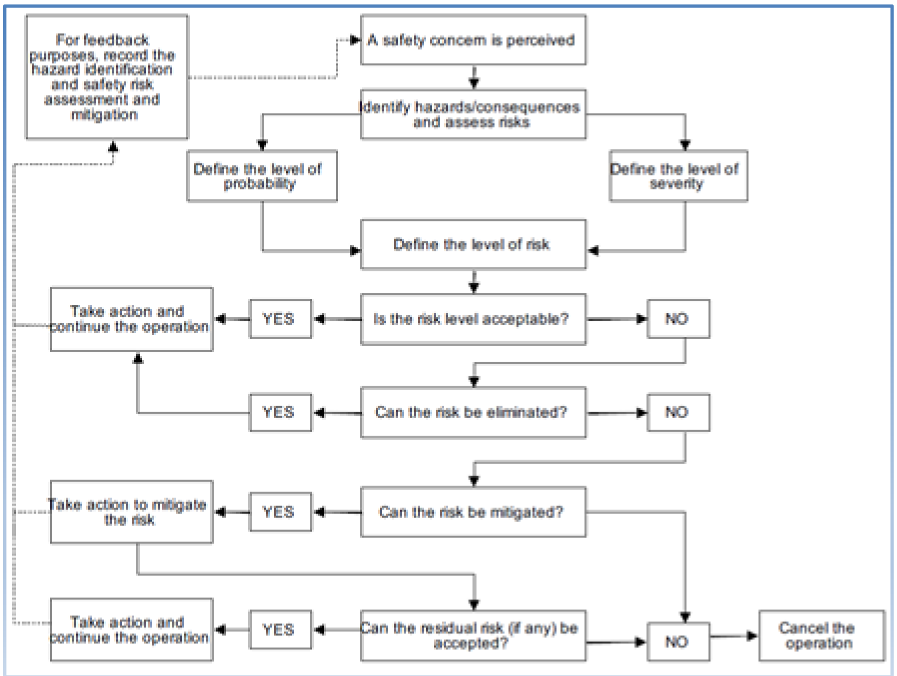


Figure 28. Safety Risk Management Process. Image: Regional Jet OÜ, MSM.

The operator used a risk register to register hazards and risk levels. Each identified hazard was described in the log, followed by the existing potential outcomes (consequences) and the risk prior to application of controls (safety barriers) to mitigate the hazard. After application of safety barriers, a new risk assessment was performed, and a final risk level was established.

In the risk register, maintenance missed or not accomplished were assessed in regards to line maintenance, base maintenance, scheduled and unscheduled maintenance actions with poor control. Several hazards were mentioned; communication error, time pressure, lack of planning, CAME[26] procedures not followed and more. Example of possible outcomes were; Flight cancellation, flight delay, increased workload, temporary ceased operation. All the risks mentioned were assessed in one and the same analysis. This resulted in an overall risk level (severity and probability), which was graded to a significant reduction in safety margins (Major) which is expected to occur every year (Remote).

The Management of Change process (MoC[27]) did not require a MoC for new maintenance contracts when the initial contract was signed (2016). However, such a requirement has been added in MSM 2018. No MoC on the maintenance contract has been performed retroactively.

[25] ALARP – As Low As Reasonably Practicable.
[26] CAME – Continuing Airworthiness Management Exposition.
[27] MoC – Management of Change.

1.17.3 *Operational Manual (OM-B), Regional Jet OÜ*

The operator's OM-B stated the following related to the handling of nose wheel steering.

Taxi

"Do not start a turn until sufficient forward speed has been attained to allow the airplane to turn at idle thrust. (Nosewheel should not be turned when aircraft is static)."

Nose wheel/rudder pedal steering

"During a turn, maintain positive pressure on the nose steering tiller to prevent the nose gear from returning to center abruptly. Straight-ahead steering and large radius turns should be accomplished with rudder pedal steering only. Avoid stopping the airplane in a turn, as excessive thrust will be required to start taxiing again. After completing a turn, and prior to stopping, center the nosewheel and allow the airplane to roll straight ahead for short distance."

1.17.4 *Maintenance organisation, SAMCO*

SAMCO Aircaft Maintenance B.V. is headquartered in Maastricht Airport, Netherlands. At the time of the incident SAMCO was an approved maintenance organisation according to Part-145 with approval number NL.145.1120. The organisation had an approval for Base and Line maintenance on Bombardier CL-600-2C10/-2D15/-2D24/-2E25 (CRJ700/705/900/1000).

Maintenance Organisation Exposition (MOE[28])

Line Maintenance Planning

The Maintenance Organisations MOE described that line maintenance planning was performed based on the customer's orders or line maintenance forecasts. The daily planning was performed by the line station's Unit Maintenance Supervisor (UMS) or certified staff member at the line station.

By reviewing the customer's line maintenance orders or line maintenance forecasts the Unit Maintenance Supervisor (UMS) or lead certifying staff member shall verify whether the requested tasks are within SAMCO approved scope of work and if it could be performed at the line station with the available resources (tooling, equipment, facilities, components, parts, documentation or manpower) and downtime. If not, the Unit Maintenance Supervisor (UMS) or lead certifying staff member would inform the Line Maintenance Manager of the additional requirements.

[28] MOE – Maintenance Organisation Exposition.

During interviews, it has emerged that at line stations with only one certified staff member, the line maintenance planning was performed by the same person. This was also the case with this current replacement of the rudder control sensor.

Performance of maintenance

The organisation had established procedures to ensure that an error capturing method was implemented after the performance of any critical maintenance task. They also had procedures to ensure that the risk of multiple errors during maintenance and the risk of errors being repeated in identical maintenance tasks were minimised. The requirement to register relevant critical steps in the aircraft's technical logbook at line maintenance, was not described in the MOE procedures.

As error capturing methods after a critical maintenance task, independent inspection was applied. In unforeseen circumstances re-inspection were applied as an error capturing method.

According to the MOE, the replacement of the rudder control sensor was not classified as a critical maintenance task.

1.18 Additional information

1.18.1 EU regulations regarding continuing airworthiness

Commission regulation (EU) No 1321/2014 on continuing airworthiness[29] aims to ensure that aircraft fulfil the applicable airworthiness requirements and are in a state that allows safe flight throughout their entire life-span. In order to achieve this objective, there are a range of different rules for various organisations and people who operate within organisations that work with continuing airworthiness.

Production planning[30]

The regulation describes that the Maintenance Organisation (Part-145) shall have a system appropriate to the amount and complexity of work to plan the availability of all necessary personnel, tools, equipment, material, maintenance data and facilities in order to ensure the safe completion of the maintenance work.

Acceptable means of compliance[31] describe acceptable ways of complying with the regulatory requirements, which, if complied with, would lead to the requirements being met. Depending on the amount and complexity of work generally performed by the maintenance organisation, the planning system may range from a very simple proce-

[29] Commission regulation (EU) No 1321/2014 of 26 November 2014 on the continuing air worthiness of aircraft and aeronautical products, parts and appliances, and on the approval of organisations and personnel involved in these tasks.
[30] Commission regulation (EU) No 1321/2014, Annex II (Part-145), 145.A.47 a).
[31] ED Decision 2016/011/R, AMC 145.A.47(a).

dure to a complex organisational set-up including a dedicated planning function in support of the production function.

For the purpose of Part-145, the production planning function includes two complementary elements:

- Scheduling the maintenance work ahead, to ensure that it will not adversely interfere with other work as regards the availability of all necessary personnel, tools, equipment, material, maintenance data and facilities.
- During maintenance work, organising maintenance teams and shifts and provide all necessary support to ensure the completion of maintenance without undue time pressure.

Performance of maintenance[32]

The Part-145 organisation shall establish procedures to ensure that an error capturing method is implemented after the performance of any critical maintenance task.

Acceptable Means of Compliance (AMC 145.A.48 (b) describes an acceptable way to meet the requirements for establishing procedures to ensure that an error-capturing method is applied after the implementation of critical maintenance tasks.

(AMC 145.A.48 (b) point (a) specifies the maintenance tasks that could be classified as a critical maintenance task. It is also up to the maintenance organisation to identify critical maintenance tasks, based on an analysis of data sources listed in (AMC 145. A.48 (b) point b), which if complied with, leads to compliance with the regulatory requirement.

The organisation shall also establish procedures to ensure that the risk of multiple errors during maintenance and the risk of errors being repeated in identical maintenance tasks are minimised.

AMC 145.A.48 (c), point (a) (2) states that the procedures should aim at minimising multiple errors and preventing omissions. Therefore, the procedures should specify how the grouping of tasks for sign-off[33] makes it possible to clearly identify critical steps.

1.18.2 Similar occurrences

The type certificate holder has compiled reported incidents where steering in the opposite direction to rudder pedal deflection has occurred after replacement or adjustment of the rudder control sensor (RVDT) has been performed.

[32] Commission regulation (EU) No 2020/270, Annex II (Part-145), 145.A.48 b), c).
[33] Sign-off – a statement issued by the ‘authorised person’ which indicates that the task or group of tasks has been correctly performed. A ‘sign-off’ relates to one step in the maintenance process and is, therefore, different to a certificate of release to service.

After 2015, four incidents have been reported for this aircraft model. In 2020, two incidents were reported at intervals of only one month, with the current incident being one of them.

1.18.3 Actions taken

The Type certificate holder

Due to the incident and other reported similar occurrences, MHIRJ has taken the following actions:

A message to all operators "All Operator Message" (AOM 700–1198) has been issued. The message focuses on the fact that temporary revisions have been performed in the Aircraft Maintenance Manual (AMM) related to removal, installation, rigging and functional check of the rudder control sensor (RVDT), also referred to as Rudder Pedal Command Module.

Revisions that have been implemented are clarification of procedures, new access procedures and revised or new illustrations. In the rigging procedure, one step has been added, which enables a verification that the sensor (RVDT) shaft is correctly oriented via the maintenance computer in the cockpit.

The operators Continuing Airworthiness Management Organisation (CAMO)

The organisation has performed or plan to perform the following actions:

- In response to the contributing factor in chapter 3.2 of this report:

  Strengthen the organisation with a new Safety & Reliability Engineer position. Duties and responsibilities will include, among others, to support the manager and direct the airworthiness organisation in the risk management process.

- In the maintenance planning process, more efficiently evaluate work content and complexity before issuing work orders.

  Established maintenance planning procedure in the Joint Procedures Manual between the Operators airworthiness organisation and contracted maintenance organisation where planning is described in detail.

- Establish a policy for critical maintenance tasks.

  Implemented a procedure to establish and identify critical tasks in CAME.

- Inform maintenance organisations about the importance of an efficient maintenance planning process.

  Included information into Joint Procedures Manual between operator airworthiness organisation and contracted maintenance organisation with meetings where maintenance planning will be reviewed taken into consideration the depth and complexibility of each planned task.

- Focus on the maintenance planning process and the process of identifying critical maintenance tasks when reviewing maintenance agreements between maintenance organisations and Regional Jet OÜ.

  Amended CAME where the airworthiness organisation included additional information.

- The intention of the airworthiness organisation is to revise all JPM manuals between the operators airworthiness organisation and contracted maintenance organisation to reflect about critical tasks and maintenance planning.

- Contracted maintenance organisation audits setup will be revised with the intention to introduce a pre-audit meeting together with airworthiness organisation to determine focus areas for each maintenance organisation based on its individual performance.

The airport's rescue service

After the incident, the airport's rescue service has established that the charger for the handheld aircraft radio was out of order. A new charger has been installed and a routine to ensure its operation has been introduced.

1.19 Special methods of investigations

None.

2. ANALYSIS

2.1 Sequence of events

2.1.1 Preconditions

The flight was a scheduled flight from Gällivare to Stockholm via Arvidsjaur. The weather conditions were good before the flight. The pilots had been off for two days and can therefore be assumed to have been rested. The planning for the flight could be carried out without stress and the crew was aware that technical maintenance had been performed on the aircraft’s nose wheel steering system the previous day.

2.1.2 Engine start and taxi-out

After starting the engines, the rudder deflection was checked and then the nose wheel steering was ARMED. There was no procedure to check if the nose wheel steering with the rudder pedals steered in the correct direction. The commander has stated that during the taxiing he primarily used the nose wheel steering tiller to manoeuvre the aircraft. This meant that there were small opportunities for the commander to perceive that the nose wheel steering via the rudder pedals turned the nose wheel in the wrong direction and steered the aircraft in the opposite direction.

The operator’s operational manual (OM-B) states that during taxiing straight ahead and at turns with a large turning radius, steering should be performed with the rudder pedals. However, this is a recommendation and not a mandatory instruction. The type certificate holder manuals do not state any recommendations for how steering should take place during taxiing. The taxiing out had two sharp turns and a longer distance with taxiing straight ahead. If the rudder pedals had been initiated for steering during the part of the taxiing that was straight ahead, it is possible that the pilot could have noticed that the aircraft steered in the opposite direction. During interview, it has emerged that the commander was accustomed to apply the nose wheel steering tiller for the nose wheel steering from other aircraft types and therefore handled the nose wheel steering in the same way. Using a learned action pattern from a situation even in new situations is usually called cognitive transfer[34].

At the end of the runway, the commander turned around the aircraft in a narrow-left turn and did not correct the aircraft’s position to stand on the centreline. He therefore stopped a little to the left of the centreline. The commander prioritized using all available runway more than standing in the middle of the center line, which could be adjusted at the beginning of the take-off roll.

[34] Cognitive Transfer – the ability to apply knowledge, skills, and practices across time and contexts.

2.1.3 *Take-Off*

The commander had his left hand on the pilots control wheel, his right hand on the throttle and manoeuvred the aircraft with the rudder pedals during take-off. When the engine speed stabilized, the commander released the brakes and moved the throttles toward the TOGA position. The aircraft began to roll and immediately turned to the left.

In Figure 29, flight data from section 1.11 are presented to show relevant parameters during take-off. The flight data shows that even before the aircraft begins to accelerate, there is a small rudder pedal deflection to the right. It is not possible to determine the position of the nose wheel when the aircraft has stopped because it is not registered. The rudder pedal deflection to the right may still indicate that the pilot has intended to steer the aircraft towards the centre line at take-off. When the first acceleration is registered, the thrust is relatively symmetrical between both engines and the right rudder pedal deflection increases. In the flight data, there is a connection between the rudder pedal deflection and the change of course of the aircraft to the left. When the turn to the left cannot be cancelled, the pilot continues to press the right rudder pedal to full deflection.

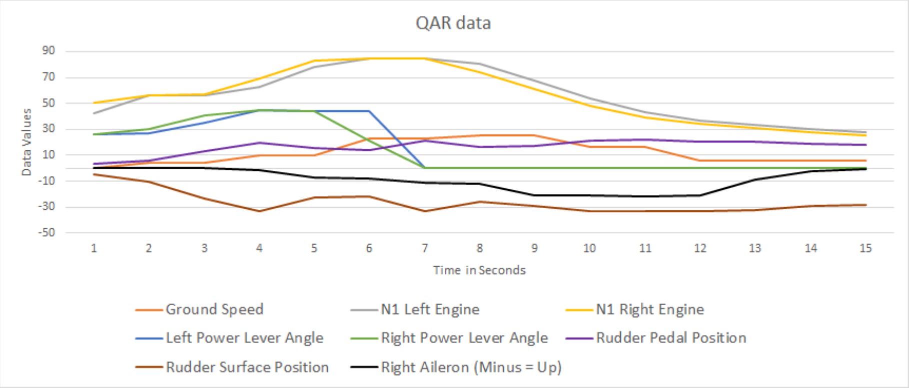


Figure 29. Registered QAR Data.

The take-off process from the time the aircraft begins to roll until the pilot abort the take-off is five seconds. It is a very short sequence where the pilot tries to analyse what is happening and act accordingly. The commander has stated that he tried to steer with the nose wheel steering tiller at the end of the take-off process. It is not possible to verify this in the flight data because the nose wheel steering tiller deflection for the nose wheel steering is not registered. The nose wheel steering via the nose wheel steering tiller has authority over the rudder pedals, which would have meant that the turn to the left could have been cancelled if the nose wheel steering tiller had been used (see section 1.6).

What also appears from the flight data and the animation is that an aileron deflection is initiated during the take-off process. The aileron deflection is controlled by the pilots control wheels on the control columns and at the incident, they were turned to the right (see Figure 29 and in section 1.11.3 Figure 17).

The deflection of the ailerons gradually increased to full deflection after the take-off was aborted and maintained until the stop. At take-off, the commander had his left hand on the pilot control wheel and if he intended to use the nose wheel steering tiller for the nose wheel steering, he had to release the pilots control wheel. The aileron test that was performed showed that the aileron system and the pilots control wheel return to the neutral position if it is released. The co-pilot has stated that he was not involved in the control and operation of the aircraft during the take-off. Overall, it is therefore probable that the commander’s experience was that he turned the nose wheel steering tiller for the nose wheel steering, but in fact he turned the pilots control wheel on the control column, this resulted in the aileron deflection during the event.

The aircraft continued to turn left after the take-off was aborted and finally stopped with the nose wheel off the runway. As there was no imminent danger, the aircraft was not evacuated. An evacuation is not without risk, and the commander's decision not to evacuate can be justified.

2.2 Survival aspects

2.2.1 The rescue operation

The fact that personnel from the airport’s rescue service saw the event meant that the rescue operation began without delay.

The fact that the rescue service own aircraft radio was without electrical power made communication with the crew on board more difficult, but in this case had a marginal impact and did not affect the outcome of the rescue operation as a whole. The measures taken by the airport’s rescue service seem to have been appropriate to the needs that arose in connection with the incident.

SHK has thus found no reason to examine the rescue operation in more detail.

2.3 Why did the nose wheel steering turn in the opposite direction?

2.3.1 Technical examination of the aircraft

During the visual inspection, it was found that the position of the rudder control sensor (RVDT) corresponded to the Aircrafts Maintenance Manual installation description.

As stated in section 1.11.1, flight data showed that nose wheel steering with the rudder pedals steered the aircraft in the opposite direction from what was expected, which was also found in the technical examination.

Inspection of the sensor shaft showed that it had a larger range of motion than normal and it also felt like there was an obstacle inside the sensor when the shaft was rotated between the end positions. This indicates that there was a mechanical fault inside the sensor without any fault warnings being detected in the system.

2.3.2 Examination of rudder control sensor (RVDT), S/N 0648

The manufacturer's investigation showed that the mechanical stop number two (clockwise stop) inside the sensor had broken off, the end of the return spring was bent and the stop cap was damaged at the end of the return spring.

The deviation of the output signal during the production test were due to the mechanical stop number two having been broken off from its original position, which meant that the sensor shaft could be turned clockwise outside the intended mechanical range.

This indicates that the sensor has been incorrectly installed at some point and that the mechanical stop inside the sensor has been broken off.

The most likely scenario for breaking the mechanical stop number two (clockwise stop) is that the missing spline on the sensor shaft is installed one tooth off (45 degrees clockwise), seen from below the sensor. Then the distance to the mechanical stop will be reduced and a deflection with the right rudder pedal, during the rigging procedure, can break the mechanical clockwise stop. However, if the sensor shaft is installed one tooth incorrectly, the rigging cannot be completed with an approved result.

If the sensor is then installed with the mechanical clockwise stop broken, the missing spline can be installed two teeth off (90 degrees clockwise) from the rig position. In this scenario, the broken stop allows the shaft to be rotated to the next quadrant's electrical zero, making it possible to rig in the sensor and get an approved result with the aircraft's maintenance computer. The nose wheel steering system cannot detect if the sensor (RVDT) signal polarity is correct or not. This meant that the clockwise stop, which in this case was broken, allowed the sensor to be rigged into another quadrant's electrical zero, without the system warning of this. The polarity of the electrical output signal will then be reversed, resulting in that steering with the rudder pedals steers the aircraft in the opposite direction.

In addition, the examination of the sensor showed no deviations within the rudder pedals range. This indicates that the sensor would probably have worked without problems if it had been installed correctly in the aircraft.

2.3.3 Memory readout and functional test of nose wheel steering ECU

The fault codes logged on 6 September 2020, i.e. the same day that an adjustment of the rudder control sensor (RVDT) was performed, are consistent with the adjustment of the rudder control sensor.

On 9 September 2020, the same day as the installation of the new sensor was performed, "RCM_REAS_FAIL" was logged. This is a check of the reasonableness with respect to the expected signal from the rudder control sensor. Reasonability monitoring (RCM) detects if the input signal from the rudder control sensor (RVDT) exceeds ± 32 degrees of shaft rotation for 100 ms or longer, which generates the fault code 000A - RCM_REAS_FAIL.

If a fully functional sensor is installed correctly according to the maintenance manual, this fault code should not be registered. If, on the other hand, the sensor is installed one tooth off from the rigging position, the reasonability monitoring will register a fault code when the power is switched on. There is also a possibility that the electrical contact is connected to the sensor and the power in the aircraft is switched on before the sensor is finally mounted, which gives several scenarios where this error can be registered. That the fault code was temporary can still be determined, since the rigging of the sensor with the maintenance computer after the installation was approved.

Based on available data and interviews, it has not been possible to determine during which part of the installation the fault code was registered.

2.3.4 Fault history, nosewheel steering

As stated in section 1.6.5, a number of remarks had been written in the aircraft's technical logbook during the summer that described a problem where the nose wheel was not centered after the aircraft had been parked for a couple of hours, without a power source or hydraulic power. The operator's airworthiness organization (CAMO) had been in contact with the type certificate holder for help in troubleshooting the problem.

The remark from 6 September 2020, where a pilot observed that the nose wheel was not centered before a flight, resulted in an adjustment of the rudder control sensor (RVDT) and the remark was closed in the aircraft's technical logbook. Based on this, the operator's airworthiness organisation again contacted the type certificate holder for help with troubleshooting.

From the type certificate holder's answer on 6 September 2020, it can be stated that the previous history where the nose wheel was not centered after the aircraft was parked for a couple of hours, without power source or hydraulic power cannot be traced to the rudder control sensor (RVDT). The recommendation to replace the rudder control sensor only applied if the problem with the fault codes related to the sensor reoccurred and if it was outside the approved rig tolerance, which was not the case.

A taxi test was performed on 7 September 2020, where the pilot experienced that the aircraft steered to the left during taxiing, without correction with nose wheel steering tiller or rudder pedals. A safety report was created but no remark was entered in the aircraft’s technical logbook.

Correction of small changes of direction during taxiing with aircraft may in most cases be considered normal to maintain a straight course. That the aircraft steered to the left during taxiing, without correction of the nose wheel steering tiller or rudder pedals may be due to wind, runway inclination, uneven engine power, unevenness on the runway or that the nose wheel steering needs to be adjusted.

The Airworthiness Organisation decided to replace the rudder control sensor (RVDT) despite the fact that there was no open remark in the technical logbook. The decision was based on the type certificate holder's recommendation together with the pilot’s safety report. The type certificate holder’s finding that the original remark where the nose wheel was not centered after the aircraft’s hydraulic power was switched off cannot be traced to the rudder control sensor. The taxi test and the content of the safety report had no relation to the original remark. Based on this, the airworthiness organisation’s decision to replace the rudder control sensor (RVDT) at the line station in Gällivare can be considered a decision that was made on incorrect grounds.

2.3.5 AMM

The maintenance manual that described the task of removal and installing the rudder control sensor (RVDT) lacked sufficiently clear instructions to get access to the unit.

There was no description of the internal mechanical stops and return spring function in the sensor. This is not typically a design of a maintenance manual installation task, but as a result, a correct verification of these functions could not be done by the technician before installation.

The figure and description in the maintenance manual on how the missing spline on the sensor should be aligned with the missing spline on the pivot assembly did not clearly described the task. In this context, it is important that the sensor is equipped with a return spring function, that the position of the sensor is difficult to access and that during installation it is almost impossible to see the missing splines on the sensor and pivot assembly.

All of these factors contributed to the sensor being incorrectly installed.

As the type certificate holder has already taken measures in accordance with section 1.18.3, SHK does not intend to issue any safety recommendations regarding this.

2.3.6 Replacement of the Rudder Control Sensor (RVDT)

The replacement of the rudder control sensor (RVDT) was considered an unplanned maintenance and was performed the day before the incident. At the time, there was no open or deferred remark in the aircraft's technical logbook regarding the nose wheel steering. The technician who was alone on duty at the line station has stated that there was no time pressure during the replacement of the sensor, which was the only work he had planned to perform during that day.

The design of the sensor means that each spline is flexible, which means that the shaft can in theory be installed in the pivot assembly for the right-hand rudder pedals in eight different ways without major resistance. The missing spline on the shaft is not a mandatory guide track but only a groove for aligning the sensor during installation. The maintenance manual described several conditions that would be met during the installation of the sensor. As stated in section 2.3.5, the instructions for how to install the sensor were not clear. During the technical examinations, installation of another sensor was performed, which showed that it was easy to install the sensor shaft incorrectly. Since this was the first time the technician performed the installation, it can be difficult to assess whether the sensor was installed correctly, based on the maintenance manual's instructions and the design of the sensor shaft. The fact that the sensor shaft had a missing spline could also be perceived as only fitting into the pivot assembly in one way.

The rigging of the sensor got an approved result without a fault warning from the system, which meant that the technician did not have to remove the sensor again. The technician has stated during interviews that he had great confidence in the system and that it warned if there was a fault.

When performing a functional test of the nose wheel steering after installation of the sensor, it must be noted whether the steering deflection is in the correct direction and a reading of the angle of the deflection must be made on the fixed degree scale on the landing gear leg. In order to be able to perform the functional test in full, two people had been needed, one in the cockpit and one at the nose landing gear. The technician, who was alone, solved this by filming the steering deflections at the nose landing gear.

Only the steering deflections with the nose wheel steering tiller were filmed. The technician has stated that he only noted that the deflections were in both directions during the test, neither the steering direction nor the angle of the deflections were verified. The steering deflections with the rudder pedals were not filmed during the test, which meant that the technician could not verify this function.

The lack of verification of the steering deflection with the rudder pedals has not been fully explained. A few days earlier, an adjustment of the rudder control sensor had been performed by the technician. After the adjustment, an operational test of the nose wheel steering was performed, where the direction of the deflection should be verified. The operational test did not include verifying the angle of the deflection. The lack of control of the angle of the deflection could indicate that the technician mixed up the tests and performed an operational test instead of the functional test.

Contributing factors may also have been that the technician had a strong belief that the system would warn and that there could have been a perception that the sensor's missing spline was a mandatory guide track that could only fit in one way. This has probably led to a lack of careful control of the rudder pedals' steering deflection regarding direction and angle.

2.4 Organisation and management

2.4.1 The operator, Regional Jet OÜ

Management System Manual (MSM) combined safety management for all parts of Regional Jet OÜ. This meant that the airworthiness organisation, which did not yet have a requirement to have a safety management system (SMS), according to the regulations, had an internal requirement for this. MSM described all applicable parts of a safety management system, hazards and risks were documented in a risk register. In the risk register, the airworthiness organisation assessed maintenance that was overlooked or not carried out with regard to line, base, scheduled and unplanned maintenance measures with insufficient control in the airworthiness organisation. This risk assessment was as close as one could get to a risk assessment that could be related to the current incident. There were no other hazards or risks in the risk register regarding routines and handling between the maintenance organisation and the airworthiness organisation. This may be because when the initial contract between the maintenance organisation and the airworthiness organisation was written, there was no process in the safety management system that handled changes (MoC). Even after the contract was updated in 2020, no MoC was performed, even though MoC was implemented at that time.

The way in which the risk register was structured and the assessments performed in relation to maintenance issues seemed, according to SHK, to have focused on commercial risks to a greater extent than flight safety risks. Although the airworthiness organisation is part of the safety management system, the organisation lacked a focus on identifying operational hazards and risks in relation to a maintenance organisation.

2.4.2 Maintenance organisation, SAMCO

Line Maintenance Planning

The maintenance organisations MOE described that line maintenance planning was performed based on the customer's orders or forecasts for line maintenance. The daily planning was performed by the line station's maintenance manager (UMS) or a certified employee at the line station.

It has emerged that at line stations, with only one certified employee, the line maintenance planning was performed by him. This was also the case when replacing the rudder control sensor.

The technician did not have any special training for his planning function or any aids regarding planning from the maintenance organisation. Although training and aids from the organisation are not a requirement, this has meant that the technician did not have sufficient conditions, which in turn has meant that he has been the only safety barrier in the planning and execution.

At the time, there were no requirements in the EU regulations for a Safety Management System that corresponds to the described standards and recommended practices according to ICAO Annex 19 for Part-145 approved maintenance organisations. Had such a requirement existed, it is more likely that an evaluation of risks and barriers to planning had been carried out, which would have provided better conditions for identifying deficiencies in the system.

Performance of Maintenance

According to the MOE, the organisation had established procedures to ensure that an error capturing method was applied after the performance of a critical maintenance task. They also had established procedures in place to minimise the risk of multiple errors during maintenance and the risk of errors being repeated in identical maintenance tasks.

In the aircraft's technical log, it was documented that the installation of the rudder control sensor was performed. No grouping of the various tasks during the installation of the sensor was on the work order from the airworthiness organisation and was not done by the maintenance organisation or the technician. There was no guidance in the maintenance organisation's MOE for how a grouping of critical steps for sign-off should be handled at line stations. If a grouping of critical steps for sign-off had been performed in the planning stage of the work, there would have been better opportunities to pay attention if deviations had been made from the maintenance manual. Even during the re-inspection performed by the technician, it had been easier to have a clear grouping for sign-off.

In summary, SHK determines that the safety barriers, which aim to ensure that the maintenance is carried out correctly, have not functioned in this case.

3. CONCLUSIONS

3.1 Findings

a) The pilot was qualified to perform the flight.
b) The aircraft had a Certificate of Airworthiness and valid ARC.
c) The day before the incident, the rudder control sensor (RVDT) was replaced.
d) The weather conditions were good before the flight.
e) The aircraft immediately turned left at take-off.
f) During take-off, the rudder pedals were used to steer the aircraft left or right around the the yaw axis.
g) Flight data and the technical examination showed that nose wheel steering with the rudder pedals steered the aircraft in the opposite direction from what was expected.
h) The maintenance manual did not describe the installation of the sensor clearly enough.
i) The function test performed after the installation of the sensor was not performed according to the maintenance manual.

3.2 Causes/Contributing Factors

The cause for the excursion was that the sensor for the nose wheel steering was incorrectly installed and that the prescribed functional test after installation of the sensor was not performed according to the maintenance manual. This led to that nose wheel steering with the rudder pedals, steered the aircraft in the opposite direction from what was expected.

Contributing factors:

- The maintenance manual lacked sufficiently clear instructions to determine the correct function of the sensor before installation.
- The description in the maintenance manual on how to install the sensor did not include sufficiently detailed instructions on how the required sensor shaft alignment could be achieved in regards to the sensor design, function and the position.
- The lack of verification of the steering deflections with the rudder pedals during the function test indicates deficiencies in the maintenance organisations and technician’s routines regarding line maintenance planning and grouping of tasks for sign-off to prevent omissions during maintenance.
- The airworthiness organisation’s participation in the safety management system lacked a focus on identifying risks between the maintenance organisation and the airworthiness organisation.

4. SAFETY RECOMMENDATIONS

None.

On behalf of the Swedish Accident Investigation Authority,

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