Saab-Scania SF340A, G-GNTF

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INCIDENT

Aircraft Type and Registration:	Saab-Scania SF340A, G-GNTF
No & Type of Engines:	2 General Electric CT7-5A2 turboprop engines
Year of Manufacture:	1988
Date & Time (UTC):	28 November 1997 at 2003 hrs
Location:	East Midlands Airport
Type of Flight:	Scheduled public transport
Persons on Board:	Crew - 3 - Passengers - 23
Injuries:	Crew - None - Passengers - None
Nature of Damage:	All tyres replaced as a precaution
Commander's Licence:	Air Transport Pilot's Licence
Commander's Age:	32 years
Commander's Flying Experience:	3,517 hours (of which 1,858 were on type)
	Last 90 days - 138
	Last 28 days - 21
Information Source:	AAIB Field Investigation

History of the flight

The first officer was to be the handling pilot for the sector. He was aged 42 years, held an Air Transport Pilot's Licence and had 2,405 hours of flying experience of which 605 were on type. He was qualified by the operator to handle the aircraft to the same crosswind limits as commanders. Normal practice in the SAAB 340 is for the pilot occupying the left seat to taxi the aircraft and align it on the runway for take off using the nosewheel steering. Irrespective of which pilot handles the take off, the left seat pilot operates the nosewheel steering during the early part of the take-off run but releases the handwheel at a pre-determined airspeed when airflow over the rudder is sufficient to provide aerodynamic directional control.

The aircraft arrived at East Midlands Airport from Aberdeen at 1705 hrs and underwent rectification to repair the left side windscreen wiper which was required to be serviceable before despatch in wet weather. At about 1945 hrs the flight crew walked out to the aircraft to prepare for a flight to Brussels. It was raining when the commander carried out an external inspection and he noted that the apron surface was wet but not flooded. The cabin crew attendant arrived at the aircraft a few minutes after the flight crew. By then it was raining steadily and she noticed that the apron was very wet under foot. After her arrival the crew had a quick status briefing before the passengers arrived on foot in what the attendant described as "pouring rain" with pools of standing water on the apron. Preparations for flight were completed uneventfully and at 1955 hrs the aircraft was pushed back by a tug. The commander noticed that it was still raining steadily as he taxied the aircraft towards the threshold of Runway 27 but he noticed nothing abnormal about the aircraft's behaviour. Whilst taxiing both pilots used their windscreen wipers intermittently and they formed the impression that the intensity of the rain had reduced slightly. Checks including full and free movement of the flight controls were completed for a 15° flap take off and the aircraft was cleared to enter the runway and depart without delay, having been passed a surface wind of 210°/19 kt. The commander aligned the aircraft with the Runway centreline and allowed it to move forward a few metres to ensure that the nosewheels were straight. At this point he reminded the co-pilot of the existence of a strong crosswind from the left before passing control of the control column and rudder pedals to the co-pilot. However, in accordance with his own customary practice the commander kept his toes on the base of the rudder pedals so that he could follow through the co-pilot's rudder pedal inputs during take off.

At 2002 hrs the commander set the Constant Torque on Takeoff (CTOT) switches to ON and placed his hands on the power levers. He noticed that the co-pilot had applied a suitable amount of right rudder to counteract the crosswind whilst he himself used the nosewheel steering to keep the aircraft aligned with the runway. Next the commander advanced the thrust levers to take-off power when the co-pilot requested it. At about 60 kt the commander released the nosewheel steering handwheel, noted the engines were stabilised within 1% of the required 103% torque and called "your controls" to the co-pilot. Moments later, at an estimated airspeed of 80 kt, the aircraft suddenly and rapidly swerved to the left. The co-pilot reported that he applied full right rudder pedal but this did not arrest the yaw and the aircraft began to travel sideways, still tracking close to the runway centreline but heading towards the left side. The commander called "Stop Stop" and took control as he retarded the thrust levers and attempted to apply more right rudder but found that full right rudder pedal was already applied. At the same time he reached over and grasped the nosewheel steering handwheel and steered into the skid in an attempt to regain directional control.

At this stage the commander had the impression that the aircraft was aquaplaning with a sideslip angle of about 50° and moving towards the left hand edge of the runway. He attempted to use reverse thrust to aid directional control and control was partially regained as the aircraft slowed. However, the commander was unable to prevent the aircraft from leaving the runway. Initially he thought that only the left main gear had tracked across the grass before he was able to turn the aircraft right relative to the runway heading and steer it back onto the concrete. It was discovered later that all three wheel sets had entered the grass. After bringing the aircraft to a halt on the runway the commander asked for the fire service to inspect the aircraft, which they did. He also spoke to the cabin crew attendant and instructed her to inform the passengers that they would be returning to the apron. After inspection by the fire crew, who reported no visible damage, the aircraft was taxied back to the apron without any further difficulty.

Meteorological information

The weather over central England was influenced by a low pressure system centred over Lancashire and it had been raining for much of the day at East Midlands Airport. From 1900 hrs until long after the incident the ATIS mentioned water patches on the runway. At 1900 hrs the surface wind was 180°/15 kt, visibility was 20 km and the cloud scattered at 1,500 feet and broken at 3,500 feet. At 1925 hrs rain was reported and at 1942 hrs the visibility decreased to 8 km. Between 1900 hrs and the incident at 2002 hrs the mean wind varied in direction between 170° and 190° and the mean speed varied between 13 and 17 kt. At 2002 hrs the ATIS reported a mean surface wind of 190°/17 kt. The QNH was 991 mb throughout the period.

Runway characteristics

Runway 09/27 has a concrete surface without grooves. Widthways it slopes slightly from north to south such that surface water has a tendency to run-off to the south side. However, southerly winds can oppose the gravitational flow of water leading to accumulations on the south side of the runway. The AGA section of the UK AIP contains a note to this effect which reads: "In conditions of moderate to heavy rain, and particularly associated with a southerly wind, pilots are advised that temporary puddles may occur on the south side of Runway 09/27".

Chapter 5 of the Manual Of Air Traffic Services Part 2 (a local document) describes the Airport's wet runway reporting procedures. It states: "Ramp Operations will, when requested, inspect the runway to provide an assessment of wet runway conditions". An assessment was carried out at 1945 hrs. An additional runway inspection was carried out at 2024 hrs when the runway state was reported as continuing to be "wet with water patches".

Flight recorders

The Flight Data Recorder (FDR) and Cockpit Voice Recorder (CVR) were returned to AAIB for replay. The aircraft was fitted with a Sundstrand UFDR and a Fairchild A100 CVR with a 30 minute recording duration.

Figure 1 shows the data from the FDR as the aircraft taxied onto the runway followed by the normal control checks. Power was applied progressively with no evidence of thrust asymmetry and, as the aircraft began to accelerate, the FDR showed that the rudder was around +20 to +25° (right rudder). This increased to +30° for around 5 seconds as the aircraft was at 20 to 30 kt before decreasing to around +10°. At around 76 kt the rudder began to move to the left, with a maximum value of -18.8° left rudder at 87 kt. This then reversed to 3.5° right rudder in a period of less than one second. There was a change in heading from 275° to 244° and with lateral acceleration of -0.28 g to the left and then 0.31 g to the right. Power was reduced and the maximum speed recorded was 88 kt. Reverse thrust was used during the deceleration.

A calibration of the rudder position measurement was carried out post incident; this was within specification. The rudder position potentiometer is located on the input arms to the rudder itself, and is therefore a good indication of surface position. The movement of the rudder pedals is not recorded.

Anomalies in recorded information

Analysis of the recorded data revealed an anomaly in that those parameters sampled more than once per second, did not update at each sample. For example, the value of normal acceleration, which should have been sampled eight times a second, was actually updated only every four to five samples. The effect was also present on the other acceleration values and also the flight control parameters such as rudder, sampled four times a second. The anomaly appeared to be intermittent such that, for some of the 25 hours of data analysed, on some occasions following recorder start up the data appeared normal. Another FDR was replayed from the aircraft post incident, this also showed the data anomaly was present but only intermittently.

The aircraft was fitted with a Telephonics Flight Data Acquisition Unit (FDAU). The FDAU was a single line replaceable unit which monitored inputs signals from serial data (RS-422 inputs from the air data system, EFIS and attitude/heading reference system), 22 analogue (potentiometer) inputs and also discrete inputs. It transmitted these values to the FDR in serial Harvard bi-phase format.

The anomaly appeared to be limited to the analogue inputs. Analogue signals 1-13 provided aircraft potentiometer derived inputs to the FDAU. The FDAU provided a reference excitation and the variation with regard to this reference was applied back to the FDAU. The potentiometer wipers were connected to various control surfaces including the rudder position. Channels 14-22 were aircraft instrumentation derived analogue inputs such as the accelerometers.

Testing was carried out at the aircraft manufacturer to identify the effect of the anomaly. Different input signals were applied to the subject FDAU and the output to the FDR monitored. Ramp inputs to the FDAU were recorded as a step function on the FDR updating approximately every 1/2 to 3/4 of a second. This showed that the value of the data was being recorded correctly, but the sample was not being updated at each sample position within the dataframe. Figure 2 shows the effect of this anomaly on the rudder position and normal acceleration with data taken from the incident flight. The data for the incident was therefore corrected by taking the first recorded value of the sample timed at that word location and ignoring subsequent repeated values. The unit was returned to the FDAU manufacturer for investigation.

Runway evidence

A series of light coloured tyre marks were left by the aircraft on the runway, beginning at a position approximately 230 metres before the intersection with taxiway Charlie, as shown in Figure 3. The first of these marks, comprising tracks from all three sets of wheels, diverged to the left at an angle of approximately 15° from runway heading, with the aircraft CG at that stage displaced approximately 4.3 metres left of centerline. The aircraft was yawed some 31° to the left, sufficient to cause the nosewheel tracks to overlay those from the left main wheels. The aircraft was therefore sideslipping to right of track, at an angle of about 16°, at that stage. The marks also show that recovery actions were initiated promptly, whilst the aircraft was still only about half way across the left side of the runway: the aircraft starting to turn rapidly to the right by that stage, achieving a 42° change of heading toward the runway by the time the aircraft's nose and right mainwheels ran onto the grass some 130 metres further on. Thereafter, the marks show the heading reducing again, as the aircraft regained the runway paved surface.

Figure 3 shows the runway tyre marks drawn to scale, with an aircraft outline overlaid onto the marks to show the aircraft yaw angle and lateral position during the excursion. Also shown in this figure are relevant parameters taken from the FDR.

Brief description of nosewheel steering and rudder control systems

The aircraft has a twin-wheel nose gear which can be turned using the hydraulically powered nosewheel steering system. There is only one steering handwheel which is located on the extreme left side of the flight deck. Depression of the handwheel energises a shutoff valve, powering the nosewheel steering hydraulic system, which allows the nosewheel to be steered by the handwheel through its maximum range of movement (50° nominal to either side). When the handwheel is released, provided the steering angle is within a nominal 20° of centre when this occurs, the nosewheel will castor freely within the limits imposed by the steering angle microswitch (20° nominal either side of centre). If the castor angle exceeds 20° nominal a microswitch is operated which causes a steering brake to cut in, 'locking' the handwheel linkage at a position which maintains the existing castor angle, and simultaneously energising a valve which powers the hydraulic system.

The following is a summary of the operation of the rudder control system but a detailed description is also contained in the maintenance manual. The aircraft is equipped with a spring tab rudder, which is mechanically actuated via a conventional arrangement of cranks, rods and cables. The system incorporates an electrically actuated gust lock mechanism, located at the base of the rudder, an electrical trim actuator also located at the base of the rudder, and an autopilot actuator which is positioned in the rear fuselage beneath the forward part of the fin. The gearing of the rudder control circuit is quite high, with a rudder pedal movement of only 74 mm to the left and 70 mm to the right. Maximum rudder displacement is limited by fixed mechanical stops at ±27.5°. At speeds above 150 kt, an electrical signal from the rudder limiter system, which receives inputs from the Air Data Computer, drives an electrical actuator to position moveable travel stops to limit rudder displacement to lesser values. If the movement of the rudder surface is constrained and rudder pedal is applied, the limit of tab movement, or control path to rudder deflection, and the resulting hard contact between the rudder actuating linkage and the rudder control surface, occurs at a rudder pedal displacement equivalent to approximately ±4° to 5° of rudder movement in normal conditions.

Examination of the aircraft

Preliminary examination of the aircraft revealed no evidence of any significant damage or malfunction.

Brakes and tyres

The anti skid system was tested by spinning the wheel transmitters, and found to function normally. The tyres were all in good condition and none exhibited evidence of transient or persistent wheel locking, or of rubber reversion. The left mainwheel tyres displayed very slight lateral scuffing. Lateral scuffing was apparent on both right main wheel tyres, predominantly on the outside edges of the outer tyre. This was consistent with the sudden yaw to the left reported by the pilots and recorded on the FDR, resulting in some 16° of sustained sideslip to the right (relative to the aircraft's path over the ground), and the consequent transfer of weight onto the right main wheels.

Both nosewheel tyres were in good condition, but significant lateral scuffing was apparent over the whole of the right hand nose tyre and the inboard half of the left nose tyre; in each case, this scuffing extended around the full circumference of the tyre.

Rudder system

The rudder system was extensively exercised on the ground to check for any evidence of slackness, sticking, or any other abnormality. The rudder moved easily through its full range of travel, reaching both limit stops without difficulty. The feel of the rudder was normal throughout, the control system appeared to be in good condition and examination of the rudder circuit's mechanical components and actuators revealed no evidence of abnormality.

Nosewheel steering system

A visual examination of the nosewheel steering system revealed no evidence of abnormality.

Preliminary checks

The nosewheels were positioned on grease plates and the nosewheel steering system exercised from the cockpit using the handwheel. The system functioned correctly, and the hydraulic pump switched in and out normally to maintain the correct supply pressure. The ground handling switch operated correctly, isolating the nosewheel steering shutoff valve. The handwheel depression microswitch operated correctly, and consistently, its operation being evidenced by audible change-over of the shutoff valve.

Operation of the steering brake microswitch system was checked by turning the nosewheel, via the handwheel, to an angle well in excess of the 20° nominal angle which should trigger changeover of these switches. After releasing the handwheel, the steering system was then operated by turning the handwheel shafting directly. It was possible to turn the shafting system easily, even though the handwheel steering brake was activated, due to the very light braking action which the unit provides. Apart from some slight lost motion, due to that inherent in the hydraulic control valve spool valve mechanism and the input linkages generally, the steering brake microswitches operated consistently and at a similar steering angle to left and right of centre. However, it was possible after slowly reducing the steering angle through the 20° nominal cut-off point to re-energise the steering system by turning the shafting back (ie so as to increase the steering angle again), the small amount of lost motion allowing the microswitch to change back and re-energise the shutoff valve. This behaviour was a feature of the design, and not indicative of any malfunction.

A subjective comparison was made between the handwheel steering brake on G-GNTF and another aircraft of the same model on the ramp at East Midlands. No discernible difference could be felt, nor was there any difference in the general feel and responsiveness of the nosewheel steering mechanism when operated in the usual manner, ie by depressing and turning the handwheel.

Rigging and performance checks

The nosewheel steering system was subjected to the full rigging and functional test procedures specified in the maintenance manual. In addition to the steering system per se, these checks encompassed all ancillary components including the weight-on-wheels switches, the ground handling switch, and the steering brake microswitch system. The steering system functioned normally throughout the tests, and both the rigging and response times were within limits. The steering brake solenoid activated at a steering angle of 20° to the left, and 21° to the right (limits: 20° ±5°).

Tests and Research

Saab Aircraft were requested by AAIB to carry out simulation runs using the company's aerodynamic computer model, to provide data traces for key parameters during a simulated take-off in which the computer model was driven using the primary control surface positions obtained from the FDR during the incident take off. The predicted response of the model was then compared with the actual behaviour of G-GNTF during the incident take off. Due to limitations inherent in the computer model, it was not possible to programme engine thrust and therefore engine power lever settings were chosen which, from experimentation using the model, provided a good match with the recorded velocity profile during the incident take off. A further limitation was that the actual nosewheel steering angle during the incident was not known, because this parameter was not recorded on the FDR. This was addressed initially by assuming a fixed nosewheel steering angle of zero degrees during the initial part of the take-off roll to 60 kt, and released so as to become fully castoring, thereafter.

Following a preliminary analysis of the results, Saab were requested to re-run the simulation under conditions in which the nosewheel actively contributed to the yaw balance of the aeroplane, ie where the nosewheel was not restricted to the straight ahead condition in the pre-release phase. This was accomplished by running the simulation using the difference between actual and simulated yaw angle to drive nosewheel steering angle demand during the active steering phase, ie for the yaw angle mismatch to provide an 'error signal' to control the nosewheel steering demand, until to the nosewheel was released and allowed to castor. Simulation runs were carried out for various release points at 60 kt, 70 kt and 80 kt.

The data from the simulations enabled comparative plots to be made of lateral acceleration, airspeed, and yaw angle in which the FDR data from the aircraft was overlaid on the simulation data.

Analysis

The crew reported that there was nothing abnormal about the aircraft's behaviour as they taxied towards the threshold of Runway 27. The commander aligned the aircraft with the runway centreline and allowed it to move forward to ensure that the nosewheels were straight. The first officer began the take-off with the commander operating the nosewheel steering while resting his feet lightly on the rudder pedals. At about 60 kt the commander released the nosewheel steering handwheel and moments later, at an estimated 80 kt, the aircraft suddenly and rapidly swerved to the left. So far as the crew were concerned, no handling issues arose during the take off which could have precipitated the sudden yaw excursion.

The geometry of the first visible tyre marks, produced as the aircraft was crossing the left half of the runway, show that it was tracking at angle of about 15° to the runway heading at that time, having already yawed through an angle of 31° to the left from its original heading on the runway centreline. The aircraft was therefore sideslipping to right of track, at an angle of about 16°, at that stage. The FDR data suggests that, as the aircraft was accelerating from 35 to 75 kt, the heading was constant with about 11° to 9° of right rudder applied. At about 75 kt the rudder began to move from this position progressively to 18° left over an interval of about 2.5 seconds. The implication is that it is the deflection of the rudder which induced the large yaw rate and caused the aircraft to diverge from the centreline. Taken at face value, therefore, it might appear that the incident can be explained simply by the crew, for some reason unknown, applying a large amount of left rudder and this was in fact the conclusion reached by the aircraft manufacturer. However, it is clearly evident from the CVR that the sudden yaw came as a complete surprise to the crew, and it is also clear from their subsequent conversations, during their taxi back to the stand and during the shut down procedures, that they were totally perplexed about what caused the sudden yaw.

It would have been illogical for the crew to apply such a large rudder deflection to the left because:

(a) The aircraft was initially tracking the centreline, in an apparently stable manner, and large rudder inputs would not have been required.

(b) The divergence to the left would have been clearly evident from visual cues and to continue to apply a large left rudder input progressively for some 2.5 seconds would have been totally inappropriate.

(c) Neither crew member recalls any significant amount of left rudder being applied during the take off, let alone such a large application.

(d) The crosswind from the left would have caused the aircraft to weathercock into the wind, ie to the left, which would have required mainly right rudder to counteract, not left.

An experienced aviation psychologist reviewed the available data. He formed the opinion that it was most unlikely that the first officer had applied what appeared on the FDR data to be a progressive and large left rudder deflection at about 80 kt thereby inducing a rapid yaw to the left. Tracking the centreline on take off is a task which requires frequent small inputs to maintain the desired track and not a single, large input of rudder deflection. Consequently, in his opinion, the cause of the sudden yaw was probably not directly linked to flight crew inputs.

This analysis therefore considers other aspects which might have influenced the event.

Potential malfunctions

Rudder system

A careful examination of the rudder circuit failed to identify any mechanical failure or abnormality, and none has been reported since the incident. The rudder control circuit is entirely mechanical, with a direct connection between the rudder surface and the pilot's foot pedals, and between the two sets of pedals. Whilst the spring tab system will absorb a small amount of rudder pedal movement without the main control surface moving, no more than about ±5° of rudder movement could have occurred before the limit of tab movement was reached, and the pilots' pedals started to move. The 18° left rudder deflection indicated in this case would therefore have moved the rudder pedals to a position equivalent to about 13° left rudder, at the very least. However, the maximum tab deflection will occur only under conditions of very high airspeeds, or in the event of a partial or total seizure of the rudder hinge. Since neither was applicable in this case, the 18° rudder deflection recorded by the FDR would have been accompanied by a significant deflection of the rudder pedals. There is negligible scope for inertial forces to develop within the rudder circuit, capable of producing an 18° rudder deflection.

The servo-actuator for the autopilot/autostab system is mechanically coupled to the rudder control circuit, and therefore any actuator inputs would have caused the whole of the rudder control system to move in response, including both sets of pilot's pedals. The only other actuators in the rudder circuit are those which engage the gust lock, and control the rudder-limiter system. A malfunction of the former would have locked the rudder in an approximately central position, and of the latter would have limited rudder travel to either 15° or 7°, depending upon the mode of failure; therefore, neither actuator system could have caused an undemanded 18° rudder deflection.

There would therefore appear to be no possibility for a large rudder deflection to have occurred without movement of the rudder pedals. It is equally clear, however, that neither pilot was aware of making such an application himself, or of it being made by the other.

Nosewheel steering

The system was correctly rigged, and its operation was checked in accordance with maintenance manual procedures. It was also subject to extensive additional checks designed to highlight any tendency toward instability or sticking, all with negative results. In short, no evidence of any defect or malfunction of the system was found which could explain the incident.

Nosewheel steering angle was not recorded by the FDR. Anecdotal evidence suggests that under certain conditions the design of the steering system makes it is possible for the nosewheel to flip through 180°, and remain in the reversed state, resulting in a reversal of steering sense when operating the handwheel. However, this condition usually arises when the aircraft is turned about a mainwheel using brakes and then allowed roll back slightly: effectively, conditions which will cause the nosewheel firstly to attempt to adopt a castor angle close to 90° in one direction, and then to be flipped beyond 90° into the reverse direction. However, in such circumstances, the rotation of the nosewheel through 180° causes failure of the electrical supply wires to the landing light which had not occurred in this case.

Mainwheel braking system

A malfunction of wheel brake system would not have been directly recorded by the FDR, but no fault was found with the braking system and the anti skid system was found to function normally. Individual brake pressures were not recorded on the FDR and it was therefore not possible to assess the effect of wheel braking or of possible asymmetric braking on the event.

Directional control

Factors which contribute to the yaw balance during take off include nosewheel steering angle, rudder deflection, and external forces such as cross-wind.

Nose wheel tyre scuff marks

The SAAB 340 nose leg is raked forward to the extent that when the nosewheels are turned to the right, the left nose tyre tends to lift partially clear the ground, and vice versa. The heavy scuffing of the right nose tyre, with negligible scuffing of the left, is therefore consistent with a steering angle to the right at the time when the scuffs were produced. The usual effect of such a steering angle would be to generate a yawing moment to the right. This is the opposite direction to the aircraft's excursion off the runway and, therefore, this scuffing must have been produced either before the initial yaw divergence or during the recovery from the yaw.

Division of directional control responsibility

During the earlier stage of the take-off run there would have been a natural tendency for the aircraft to weathercock to the left into wind. This yawing moment would normally be countered by right rudder together with inputs from the nosewheel steering. It is possible that the very wet runway could have resulted in larger than normal nosewheel angles being used (possibly greater than the 20° limit beyond which the system will remain non-castoring after handwheel release) which could also result in scuffing of the right nose tyre. In view of the need for the pilot occupying the left seat to operate the nosewheel steering during a take off handled by the pilot in the right seat, a division of responsibility for directional control is inevitable during the early part of the ground roll. Consequently, there is a small but significant risk of each pilot applying an input which is out of phase with or tending to countermand the input made by the other pilot. Opposing inputs might not be resolved until the left seat pilot releases the nosewheel steering tiller at about 60 kt, whereupon there might be a tendency for the aircraft to yaw as the nosewheels suddenly become free to castor. It is not possible to say whether or not this situation existed at the time of the incident, but it was suggested to the operator that the left seat pilot should perform all take offs in difficult conditions (such as a contaminated runway with significant crosswind).

Following the initial yaw divergence the commander considered that the aircraft was aquaplaning with an estimated 50° of left yaw but sideslipping to the right. He reported steering into the skid (to the right) with the handwheel in an attempt to regain directional control and it would be understandable in such circumstances if he had applied a significant steering angle such that the scuffs could have been caused at this stage. The presence of visible nosewheel marks from the position of maximum yaw angle onwards does indicate that slippage between these tyres and the runway was taking place at that time, and during the subsequent stages of the recovery.

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Nosewheel steering aspects

Consideration was also given to the possibility that during the initial stages of the take off the nosewheels might have been turned to the right, to counter the crosswind, by an amount just sufficient to activate the steering brake microswitch (20° nominal steering angle), causing the steering system to hold an offset to the right when the tiller was released instead of reverting to castor mode as expected. Alternatively, after the tiller was released, a gust-induced yaw may have caused the nosegear to castor briefly beyond the 20° castor limit, causing the steering brake to engage and hold the offset. In these circumstances, it would be possible for the aircraft to continue tracking straight initially, albeit with the nosewheel skidding, and for a combination of wind effects and rudder to balance this offset and maintain the aircraft tracking straight. If the steering were then to revert suddenly to castor mode, the effect would be comparable to a sudden steering input to the left. Reversion to castor mode could occur if the steering brake microswitch was only just triggered initially, after which general airframe vibration could have caused it to switch back into the <20° regime, causing the system to revert instantaneously to castor mode.

The initial runs of the computer model were made with the nose gear locked in the central position, and then released at 60 kt. In overall terms, the resulting plots correlated reasonably well with the aircraft's actual response as recorded on the FDR. However, small but significant discrepancies were noted. In particular, there was an apparent mismatch in the heading and related traces between the point of nosewheel release up to the onset of the large yaw to left, which suggested that the nosewheel on G-GNTF had not been free to castor until a speed significantly above 64 kt. Better correlation was found with the data from the revised computer simulations which were made using refined algorithms taking into account rudder tab spring stiffness and using an error feedback algorithm to drive the nosewheel steering, with nosewheel release to castoring mode taking place at a range of speeds up to 80 kt. These simulation data provided a better match with the FDR traces, particularly in the regime from 60 to 80 kt, with noticeably the better correlation being achieved on those runs when the nosewheel was released at a later stage. Whilst the model runs cannot provide conclusive results, they do suggest that the nosewheel was making an active contribution to the yaw balance of the aeroplane at speeds between 60 and 80 kt, ie the nose wheels did not revert to castoring mode from 60 kt onward, when the handwheel was released by the commander. Arguably, these results lend support for the suggestion that the nosewheel steering brake may have been holding a steering offset until it was effectively 'released' at about 80 kt.

Loss of nosewheel effectiveness

A sudden loss of effectiveness of nosewheels which are generating a sideforce because of the applied steering angle would induce a sudden yawing moment. Such a loss of effectiveness could result from a reduction in tyre friction either because the wheels encounter a patch of standing water and/or due to a reduction in nosewheel down force with the application of up elevator. In this regard, it is of note that a sharp up-elevator input, from about -7° to +4°, can be seen on the FDR trace over a one second period starting at about 80 kt. Alternatively, a reversion of the nosewheel steering to castoring mode would, as previously discussed, generate a sudden yawing moment.

Summary

It was not possible to identify the root cause of the incident. Taken at face value, the large input of left rudder, as recorded on the FDR, would appear to correlate reasonably with the behaviour of the aircraft and explain the incident. On the other hand the crew have no memory of making a large left rudder application and such action would have been totally inappropriate in a situation where relatively small inputs, mainly of right rudder, would have been required. It was also evident from the CVR that the sudden yaw came as a complete surprise to the crew and that they were totally perplexed about its cause. Once the yaw had developed, the commander's swift reactions prevented the aircraft from sliding sideways as it ran onto the soft grass. Had he been unsuccessful, side forces might have been sufficient to collapse the landing gear.

The combination of a strong crosswind from the left together with a very wet runway were major factors which reduced directional stability. A contributory factor may have been the practice of dividing the responsibility for directional control by allowing the first officer in the right hand seat to conduct the take off while the commander operated the nosewheel steering.

There was some evidence that, before the sudden yaw divergence, the nosewheel had been holding a steering offset to the right until it reverted to castoring mode at about 80 kt. It was possible that this steering offset may have been held by the steering brake mechanism. Under such circumstances the reversion of the nosewheel to castoring mode, or a loss of nosewheel effectiveness due to a reduction in friction would have induced an uncommanded yaw.