INCIDENT

Aircraft Type and Registration:	Airbus A320-214, G-BXKD
No & Type of Engines:	2 CFM56-5B4/P turbofan engines
Category:	1.1
Year of Manufacture:	1997
Date & Time (UTC):	15 January 2005 at 1635 hrs
Location:	London Gatwick Airport, West Sussex
Type of Flight:	Public Transport (Passenger)
Persons on Board:	Crew - 7 Passengers - 177
Injuries:	Crew - None Passengers - None
Nature of Damage:	Left nose wheel detached from aircraft
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	40 years
Commander's Flying Experience:	6,200 hours (of which 4,400 were on type) Last 90 days - 113 hours Last 28 days - 55 hours
First Officer's Flying Experience	4,392 hours (of which 2,566 were on type) Last 90 days - 82 hours Last 28 days - 36 hours
Information Source:	AAIB Field Investigation

Synopsis

The left nose wheel detached from the aircraft during the takeoff from London (Gatwick) Airport. Airport staff saw the wheel fall off and the flight crew were notified by Air Traffic Control (ATC). After holding for two hours, to burn off fuel and reduce the landing weight, the aircraft landed safely at Gatwick. The nose wheel detached as the result of the partial seizure of the outer wheel bearing, most probably caused by water contamination of the grease in the bearing. Four safety recommendations have been made.

History of the flight

The flight was scheduled to depart from London (Gatwick) at 1400 hrs for Sofia, Bulgaria, with an estimated flight time of 2 hours 40 minutes. The taxi and subsequent takeoff at 1434 hrs were apparently uneventful but one minute after the aircraft was airborne ATC advised the crew that they had lost a wheel on departure. The aircraft was given a radar heading and clearance to climb to maintain 3,000 ft initially and was subsequently re-cleared to climb to 6,000 ft and to hold at the nearby Mayfield VOR.

Ten minutes later ATC informed the crew that it had been confirmed that it was a nose wheel that had detached from their aircraft. With the aircraft now in the holding pattern the crew considered the options available to them. They decided to reduce the fuel load until the aircraft was at its maximum landing weight of 64,500 kg and then to carry out a landing. At first, following consultation with their company operations and engineering departments, the crew planned to divert the flight to Manchester Airport. However, on receipt of an unfavourable weather report from Manchester they decided to remain at Gatwick and complete a landing in daylight in the better weather conditions available there.

The crew, uncertain of the reason for the loss of the wheel and unable to ascertain the integrity of the nose landing gear, reviewed all the various possible consequences of making a landing. They decided to plan for the worst case, which was the nose landing gear collapsing on landing. There were no Electronic Centralised Aircraft Monitor (ECAM) messages or any other indications of a failure displayed so they reviewed the Quick Reference Handbook (QRH) and the Flight Crew Operating Manual (FCOM) looking for any procedure related to the unusual configuration of their aircraft. They eventually decided to apply the 'LDG WITH ABNORMAL L/G' procedure from the QRH. They briefed the cabin crew for an emergency landing and informed the passengers of the nature of the problem.

Although the crew now knew that they had lost one nose wheel, in order to confirm the existing condition of the nose landing gear they arranged with ATC to carry out a low approach and go-around. This was to allow company engineering personnel, positioned near the threshold of Runway 08R, to make a visual inspection of the landing gear. At 1557 hrs a flypast was carried out down to 200 ft agl, following which a normal go-around was flown but with the landing gear remaining down. After the flypast, engineering personnel advised the crew that the left nose wheel was missing but that the right nose wheel was in place.

The aircraft returned to the hold and following a further review of the QRH and the FCOM the crew decided that they were ready to make an approach. A normal approach was completed until just before touchdown when the first officer shut down both engines, as the crew had pre-planned, in accordance with the QRH procedure. A gentle touchdown followed at 135 kt with an attendant pitch attitude of 6º. The commander applied the brakes, being careful not to brake too hard since the anti-skid system was not available, and kept the aircraft rolling straight along the runway. The nose gear touched down normally. The commander experienced some difficulty in maintaining directional control, needing to brake harder on the right side to keep straight. One right main gear tyre burst but the aircraft maintained the runway centreline until just before coming to a stop, when the nose swung left through approximately 30º. The aircraft stopped having used some 2,300 m of the available runway length.

After the aircraft came to a stop the commander consulted with the Airport Fire Service (AFS) as to the condition of the aircraft and decided that a passenger evacuation would not be necessary. A wheel jack and spare nose wheel were brought out to the aircraft and once they were positioned and fitted the aircraft was considered to be secure. Steps were brought out and the passengers disembarked normally.

Runway marks

A set of tyre marks leading back from the nose and main wheels indicate that after landing the aircraft continued down the runway with each of the main wheels approximately equidistant from the runway centre line. During approximately the last 8 ft of the ground roll, the tyre marks from the right hand nose wheel tyre indicates that the nose wheel had turned approximately 60º to the left, resulting in the aircraft stopping on the runway at an angle of approximately 30º to the runway centre line.

Airport operations

Runway 08R at Gatwick has a Landing Distance Available (LDA) of 2,766 m (9,075 ft).

The AFS were already prepared for the emergency landing and the first vehicle arrived at the point where the aircraft came to a stop within a few seconds.

Following the landing the aircraft remained on Runway 08R thereby closing the operational runway at the airport. However the protected area for the standby Runway 08L was not infringed and therefore operations were quickly switched to Runway 08L. There were six diversions away from the airport before it reopened.

Meteorological conditions

The weather report received by the crew for Manchester Airport, which had been observed at 1450 hrs, was as follows: Surface wind from 150º/11 kt, visibility 5 kms, cloud overcast at 600 ft, temperature 10ºC, dewpoint 9ºC and QNH 1019 hPa.

Gatwick ATIS information 'X', valid at 1620 hrs was as follows: Surface wind from 140º/3 kt, CAVOK, temperature 8ºC, dewpoint 4ºC and QNH 1023 hPa.

The crew wished to complete the landing in daylight and verified that the local time of sunset was at 1623 hrs.

Operational decisions

Electronic Central Aircraft Monitor

The ECAM presents data to the flight crew. In the case of a failure or problem where there is no ECAM message generated the crew may be able to refer to procedures in the QRH. Further information may also be available in the FCOM which the crew should review if there is time available.

'LDG WITH ABNORMAL L/G' procedure

The diagram at Figure 1 below is included within the 'LDG WITH ABNORMAL L/G' procedure in the FCOM. It shows that in the event of a collapse of the nose landing gear both engine nacelles would contact the runway.

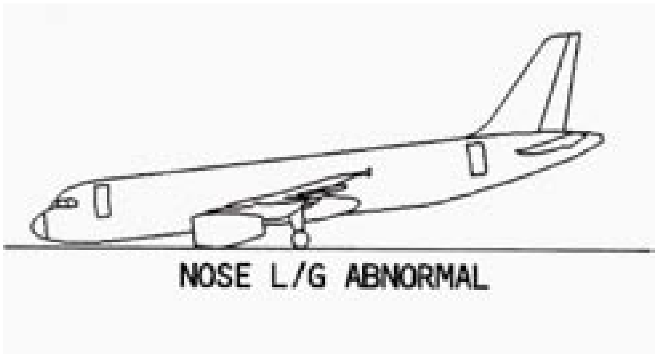


Figure 1

Nose Gear Down

The QRH procedure is reproduced below at Figure 2

Expanded information is provided in the FCOM in the form of notes within the procedure.

The procedure requires the engines to be shut down before or during the landing roll. The loss of electrical power, (without the APU running) renders some services associated with stopping distance and directional control unavailable, notably the ground spoilers, the antiskid system and nose wheel steering. Further effects due to the decay of hydraulic pressure over time are; loss of hydraulic brake pressure and loss of flight controls.

LDG WITH ABNORMAL L/G

PREPARATION

- CABIN CREW .... NOTIFY
- ATC .... NOTIFY
- GALLEY .... OFF
  - *Consider fuel reduction to a safe minimum.*
- **If NOSE L/G abnormal**
  - CG location (if possible) .... AFT
    - *10 PAX from front to rear + 4 %.*
    - *10 PAX from mid to rear + 2.5 %.*
- **If one MAIN L/G abnormal**
  - FUEL IMBALANCE .... CONSIDER
    - *Open the fuel X-FEED valve and switch off the pumps on the side with landing gear normally extended.*
- OXYGEN CREW SUPPLY .... OFF
- SEAT BELTS/NO SMOKING .... ON
- CABIN and COCKPIT .... PREPARE
  - *Loose equipment secured.*
  - *Survival equipment prepared.*
  - *Belts and shoulder harness locked.*

APPROACH

- GPWS SYS .... OFF
- L/G LEVER .... CHECK DOWN
- GRVTY GEAR EXTN handcrank ..... TURN BACK TO NORMAL
- AUTOBRAKE .... DO NOT ARM
- EMER EXIT LT .... ON
- CABIN REPORT .... OBTAIN
- **If one or both MAIN L/G abnormal**
  - A/SKID & NW STRG .... OFF
  - MAX BRAKE PR 1000PSI
  - GROUND SPOILERS .... DO NOT ARM

BEFORE LANDING

- RAM AIR .... ON
- BRACE FOR IMPACT .... ORDER

Cont'd

LDG WITH ABNORMAL L/G (cont'd)

FLARE, TOUCHDOWN AND ROLL OUT

Engines should be shut down sufficiently early to ensure fuel is shut off before the nacelles impact, but sufficiently late to ensure adequate hydraulic supplies for the flight controls. Engine pumps continue to supply adequate hydraulic pressure for 30 seconds after first engine shutdown.

- REVERSE .... DO NOT USE
- **If NOSE L/G abnormal**
  - NOSE .... MAINTAIN UP
    - *After touchdown, keep the nose off the runway by use of the elevator. Then, lower the nose onto the runway before elevator control is lost.*
  - BRAKES (compatible with elevator efficiency) ..... APPLY
  - ENG MASTERS .... OFF
    - *Shutdown the engines before nose impact.*
- **If one MAIN L/G abnormal**
  - ENG MASTERS .... OFF
    - *At touchdown, shut down both engines.*
  - FAILURE SIDE WING .... MAINTAIN UP
    - *Use roll control, as necessary, to maintain the unsupported wing up as long as possible.*
  - DIRECTIONAL CONTROL .... MAINTAIN
    - *Use rudder and brakes (maximum 1000 psi) to maintain the runway axis as long as possible.*
- **If both MAIN L/G abnormal**
  - ENG MASTERS .... OFF
    - *Shut down the engines in the flare, before touchdown.*
  - PITCH ATTITUDE (at touchdown) .... NOT LESS THAN 6°

WHEN A/C STOPPED

- ENG (all) and APU FIRE pushbutton .... PUSH
  - *Pressing the ENG FIRE pb shuts off the related hydraulic pressure within a short time.*
- ENG (all) and APU AGENT .... DISCH
- EVACUATION .... INITIATE
  - *Announce : "PASSENGER EVACUATION" via the P.A. system, and press the EVAC COMMAND pushbutton.*
  - *All emergency and passenger doors may be used to evacuate the aircraft.*

Figure 2

It was following an accident to an Airbus A340 aircraft at London Heathrow, reported on in AAIB Aircraft Accident Report 4/2000, that changes to Airbus QRH procedures were made which allowed for consideration of the best timing for engines to be shutdown when landing in an abnormal configuration. The changes were made with the intention of:

> *'preserving essential electrical and hydraulic services for the maximum time consistent with the reduction of risk to the aircraft.'*

Flypast

The initial idea for a flypast was suggested by company engineering personnel and passed on to the crew by ATC. The crew readily complied with the suggestion. There was not any procedure or training for how to carry out a flypast so the crew discussed beforehand how they would fly it. Initially they planned to go down to 500 ft agl in the landing configuration and then to fly level past the runway threshold. However once they had descended to 500 ft agl on the approach they realised that it would not be low enough for anything to be seen, so they continued down to 200 ft agl. The go-around was flown as a standard procedure with the exception that the landing gear remained down.

Approach and landing

The crew followed the QRH procedure (Figure 2) and completed the actions as required. There were two variations made to the procedure, firstly they applied the 'GROUND SPOILERS..............DO NOT ARM' action, applicable for when one or both main landing gear are abnormal and secondly the engine masters were selected to 'OFF' just before touchdown.

Landing distance

The procedure provided for calculating landing distance requires a base figure to be determined and then correction factors are applied according to the nature of the failure. Correction factors for a number of different failures or combination of failures can be obtained from the QRH but there were none directly applicable to these particular circumstances. The factor to be applied for a loss of green and yellow hydraulic systems (ie for accumulator braking only) is 2.6 times the normal landing distance, which in this case would have given a figure of 2,500 m.

Damage to the aircraft

Apart from the missing left hand nose wheel, the only apparent damage to the aircraft was a burst starboard main wheel tyre and scuffing to the outboard edge of the remaining nose wheel tyre. The axle for the missing nose wheel and the wheel nut securing threads were undamaged, with no signs of overheating. There were minor scratches on the sleeve that covers the axle, which most probably occurred during routine maintenance operations. The operators maintenance staff inspected the nose wheel bay and adjacent structure in accordance with instructions from the manufacturers and found no damage. The nose undercarriage leg was replaced as a precautionary measure. Detailed examination of the burst main wheel tyre and anti skid system was not carried out as the action of shutting down the engines rendered the anti skid system inoperative and the tyre was seen to burst half way through the landing ground run.

Aircraft Information

Nose Wheel Assembly

The nose wheel assembly consists of two wheels each running on an inner and outer bearing that sits on a sleeve fitted over the axle (Figure 3). A circlip secures the bearing in the wheel hub during transportation. Grease seals are fitted on the outside face of both bearings and the wheel is secured to the axle by the nose wheel securing nut, which has a right hand thread. Secondary locking of the nose wheel securing nut is achieved by two locking bolts fitted with castellated nuts and split pins. The hub cap is secured by three securing bolts.

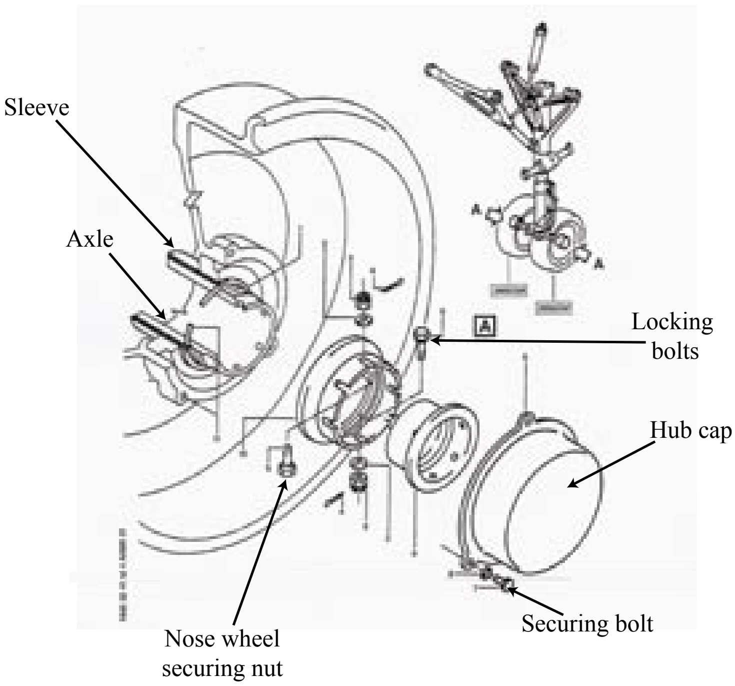


Figure 3
General Arrangement of Nose Wheel Assembly

Bearing

The nose wheel bearing consists of a cone, taper roller, cup and cage (Figure 4). The cup is fixed to the hub and is not normally replaced at wheel overhaul unless there is any evidence of physical damage. The tapered rollers are spaced and retained on the cone by the cage. The radial and side forces on tapered roller bearings are reacted primarily by the tapered races and roller bodies, and also by the roller large end and cone large rib faces.

Detailed Examination

Definition of Roller End Scoring

Roller end scoring results from metal to metal contact between the roller large end and cone rib face. In normal operation the roller body rolls along the face of the cone, whilst the roller large end moves with a sliding and rolling motion across the cone large rib face. However, if the load between the roller large end and rib face is too high, or there is insufficient lubrication, then metal to metal contact between the roller large end and rib face could occur. This contact may result in the micro-welding and tearing of metal causing excessive heat to be generated. The increase in friction at the roller large end would cause the rollers to start to skew and slide along the cone face, causing the softer cage pockets to be distorted. A further increase in temperature might be sufficient to cause the rollers to weld to the cone and 'bearing lock up' to occur.

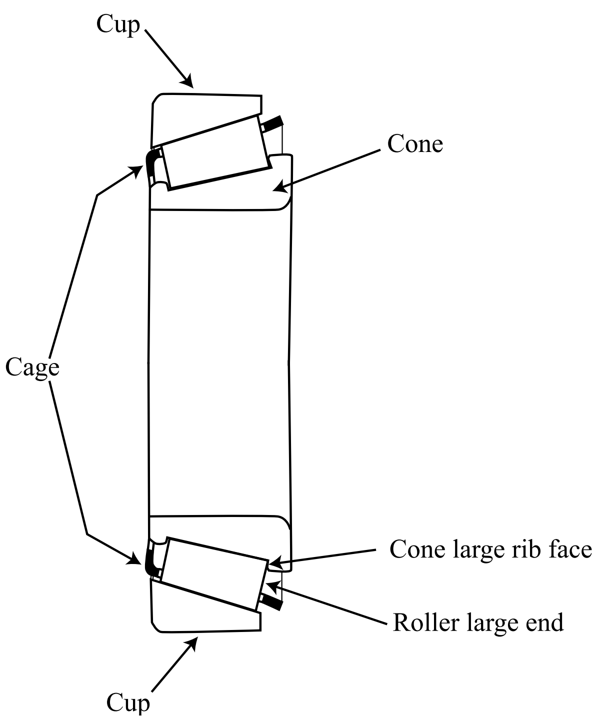


Figure 4

General Arrangement of Nose Wheel Bearing

Examination carried out at incident site

The left nose wheel, which was found near the runway, appeared to be in good condition with no evidence of either scuffing of the tyre, or damage to indicate that it had fallen from the aircraft. Whilst the inner bearing cone and securing circlip were missing, the inner bearing cup was still attached to the wheel. The hub cap was still in place and the three securing bolts were correctly wire locked. It was noted that a small quantity of grease had been thrown out from under the hub cap across the outer face of the wheel. On removing the hub cap it was observed that the grease under the hub cap and on the bearing was a chocolate brown colour rather than the normal bright red. The nose wheel securing nut was stuck to the grease seal and, apart from slight damage to the last thread, the nut was found to be undamaged. The tails and one head of the two nose wheel securing nut locking bolts, which had failed in shear, were found in the grease. The split pins in the locking bolts were still in place and correctly fitted. Slight damage was found on the castellation of the nose wheel securing nut consistent with it having sheared the locking bolts. The bearing was rotated through approximately 180°; whilst it was free to rotate the bearing felt very rough and required a moderate amount of force to keep it moving. Both nose wheels were subsequently taken to the operator's wheel overhaul agents to be stripped and examined under AAIB supervision.

Examination carried out at wheel overhaul facility

The outer bearing assembly, on the recovered left nose wheel, had been correctly fitted and the circlip was still in place; the quantity of grease in the bearing was considered to be adequate. The bearing cup was removed and grease samples were taken at a number of positions through the hub. It was noted that the colour of the grease gradually changed from the chocolate brown at the outside face of the bearing towards the more normal reddish colour on the inner face of the bearing. Fitters experienced in handling this type of wheel indicated that the grease was normally chocolate brown on returned wheels. From the bearing (Figure 5) it could be seen that the rollers had been forced under the bearing cage and that the softer cage had been distorted, with metal transfer having occurred between the cage and bearing cup. Metal smearing was discovered around the circumference of the bearing cone in a position consistent with the distortion and damage to the bearing cage. Apart from localised bluing at the large end of the bearing rollers and a light straw colour on part of the cone, there was no indication that the hub, axle or other wheel components had been subjected to high temperatures. Because of distortion to the outer bearing seal it was not possible to check the dimension of the seal using the seal gauge. The inner bearing cone was removed, inspected and found to be in a good condition.

Figure 5

Left hand wheel outer bearing

The bearing assemblies and associated components in the right nose wheel were all found to be serviceable. Again, the colour of the grease appeared to change through the hub, with the grease on the inner bearing much closer in colour to that of new grease. Both bearing seals marginally failed the seal check, which is not surprising given that the wheel was half way through its anticipated overhaul life and the test is designed to check that the seals are suitable for reissue.

Examination at bearing manufacturer

The outer bearing from the left nose wheel was stripped and examined by the manufacturer under AAIB supervision. It was established that the bearing had the correct part and hardness number. The bearing and grease seals were measured and, as far as could be ascertained, were considered to be manufactured to the correct dimensions. The outer grease seal and securing nut were separated and it was observed that there was wet grease between the contact surfaces. An inspection of the contact faces between the grease seal, securing nut and cone indicated that fusion between the cone and grease seal was caused by cold welding and between the securing nut and grease seal by melted paint from the grease seal.

The cage, which was distorted, was cut open to allow the bearing to be inspected. (Figures 6 and 7) The cage pockets were skewed and metal transfer had occurred between the cage and cup, approximately 5 to 10 mm from the roller large end. Four of the rollers were welded to the race at an angle of approximately 16º and there were marks around the remainder of the circumference indicating that the remaining rollers had been spot welded to the cone race. The roller large ends were slightly deformed with metal smearing and signs of bluing, which indicates temperatures above 815ºC. A number of the rollers also exhibited metal smearing and a flat spot within 10 mm of the roller large end, which indicates that the rollers had skidded for a short period. The cone large rib face exhibited signs of plastic deformation and bluing around its circumference. The cup displayed evidence of light straw discolouration, indicating temperatures of approximately 238ºC, and metal smearing 5 mm deep around the circumference of the race, which matched the metal smearing on the cage.

The cup from the left nose wheel inner bearing was assessed to be in good condition and suitable for further service. The inner and outer right nose wheel bearings were also assessed as being serviceable for further use.

Grease Examination

The quantity of grease recovered from the bearings was relatively small and, therefore, limited the number and types of tests that could be carried out. A test to establish the water content revealed that in the bearings fitted to both nose wheels, the amount of water present in the grease in the outer bearings was significantly higher than in the grease in the inner bearings. See Table 1.

Figure 6 (left)
Rollers welded to cone

Figure 7 (right)
Distortion of cone large rib face

Sample	Water Content %
Sample of fresh Grease of Mobil Grease 28	0.07
Left hand wheel – under hub cap	22.5
Left hand wheel – Under outer seal on outer bearing	15
Left hand wheel – Outer bearing, on bearing surface	22.6
Left hand wheel – Outer bearing, inner race	22
Left hand wheel – Inner bearing, on inner cone	2.1
Right hand wheel – Outer bearing under outer seal	18.3
Right hand wheel – Outer bearing under outer seal	25.1
Right hand wheel –Inner bearing under outer seal	2

Table 1

Water Content in Grease Samples

A further 6 grams of grease from the left outer bearing was analyzed by Fourier Transform Infrared spectroscopy and the spectra were compared to a sample of Mobil Grease 28, batch number B98259 manufactured in December 2004. It was concluded that the grease in the bearing was Mobil Grease 28 and that there was no sign of oxidization. Oxidization occurs when grease is subjected to elevated temperatures; however it is possible that grease exposed to localised high temperatures might have boiled off leaving no detectable trace of oxidization.

Further grease samples were taken from the nose wheels of ten A320 aircraft of four different operators that had operated in similar conditions in Northern and Southern Europe over the winter period. The grease taken from six aircraft from the same fleet as the incident aircraft had a water content of 0.6% to 5.3% with an average of 2.6%. The water content on the remaining aircraft was less than 1% with an average of 0.43%. The four airlines used three different types of grease.

Research

Effect of water on the lubricating properties of greases

The QinetiQ Fuels and Lubrication laboratory have previously undertaken work into the effect of water on the lubricating properties of greases. A Cone Penetration, Mean Hertz Load and Welding Load tests were undertaken to determine the effect on the properties of grease with a water content of 18% to 25%. Mobil Grease 28 has a clay (Bentonite) thickener and the consistency of the grease measured by the Cone Penetration Test, after working the grease by 60 double strokes, revealed that the hardness had increased by 38 units, which took it outside the limitations detailed in the Defence Standard. The Mean Load Test recorded a decrease in the load carrying capability by 36% and the Welding Load Test recorded a reduction in the extreme pressure lubrication ability of 20%. The studies concluded that the contamination of grease within a bearing by water can have a significant effect on some of its important physical and mechanical properties such that bearing failure may occur.

Landing mass and fuel burn

The aircraft actual take-off mass was 70,268 kg which included 10,200 kg of fuel. The maximum landing mass for this aircraft was 64,500 kg and the actual landing mass of the aircraft was 63,568 kg with 3,500 kg of fuel remaining on board.

A flight simulator was programmed with a similar aircraft weight and environmental conditions and at holding speeds at 6,000 ft the following fuel burn figures were observed (see Table 2):

Autopilot engaged, no spoiler	2,500 kg/hr
Autopilot engaged, half spoiler deployed	3,000 kg/hr
Manual flight, full spoiler deployed	4,000 kg/hr
Landing gear extended	3,600 kg/hr
Landing gear and spoiler extended, autopilot engaged	5,000 kg/hr

Note 1. With autopilot engaged only reduced spoiler deflection is available
Note 2. With APU running fuel burn increased by approximately 50 kg/hr
Note 3. An increase in speed was required when spoilers were extended

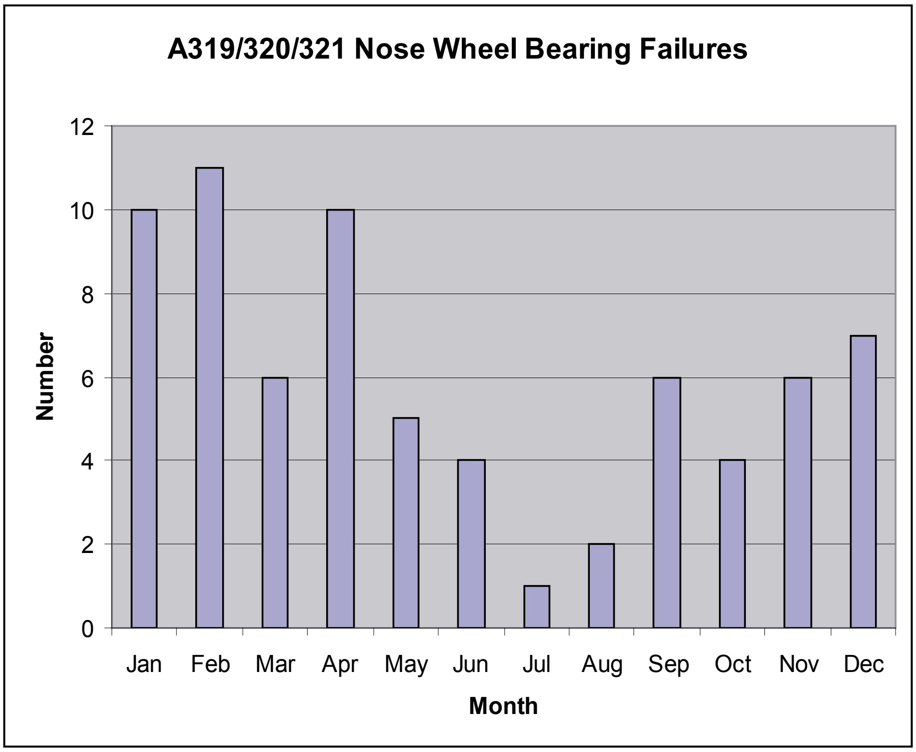
Table 2

Fuel burn at various configuarations

Previous Incidents

Data provided by the aircraft manufacturer indicated that there had been 74 reported occurrences of problems with the nose wheel bearings on the A319/320/321 family of aircraft since 1989, which resulted in seven nose wheels coming off aircraft operated by six different airlines. Four of the incidents involved the left wheel. Approximately 44% of the occurrences involved the new wheel assembly (3-1531), of which 28% involved the outer bearing. The majority of the airlines that have reported problems operate in the Northern Hemisphere and it would appear from the data that there might be a seasonal connection. However, given the size of the fleet and the number of cycles flown since 1989 care must be taken in how this relatively small number of occurrences is interpreted. (See Graph 1.)

Following the early failures an investigation was undertaken by the aircraft, wheel and bearing manufacturers who determined that the failure mode of the bearing was roller end scoring, resulting from excessive rib stress. In the subsequent years a number of measures were introduced such as increasing the bearing preload and reducing the aircraft speed when undertaking sharp turning manoeuvres. A number of modifications to the wheel assembly were also made including the introduction of a new improved wheel (PN 3-1531), which featured bigger bearings and improved spacers and grease retainers. A new grease seal inspection criteria was also introduced, by a Service Bulletin, in July 2004, which the wheel manufacturer believed would help ensure that fully worn grease seals were not refitted in nose wheel assemblies. Since this incident the wheel manufacturer has introduced an improved grease seal, which they believe makes the ingress of contaminants and the leakage of grease more difficult.



Graph 1

However, water ingress tests, undertaken by the wheel manufacturer, produced inconsistent results and it was not possible to determine if the new seal was any better at preventing the ingress of water.

Not only did the last three occurrences of wheels coming off aircraft involve the improved wheel, but the manufacturer's tests did not demonstrate that the new seal is any more effective at keeping out water than the seal fitted to the incident wheel. This suggests that the fundamental causes of the bearing failures might not have been resolved.

Flight Recorders

CVR

The aircraft was fitted with a digital cockpit voice recorder (CVR) capable of recording the P1, P2 and cockpit area microphones on a 2-hour continuous loop when AC power was available. As the flight duration was greater than 2 hours, the recordings during the take-off were over-written; the recorder stopped when the AC power supply was interrupted when the engines were shut off about three seconds after the aircraft touched down at Gatwick Airport. The subsequent landing roll was thus not recorded. Interruption of the power supply to the CVR and FDR is discussed later.

FDR

The aircraft was fitted with a digital flight data recorder (FDR) capable of recording a comprehensive range of parameters on a 25-hour continuous loop. Like the CVR, the FDR stopped recording when the AC power supply was interrupted after the engines were shut off.

From the available parameters on the FDR, there were no unusual occurrences such as fast or extreme manoeuvring on the ground in the recorded sectors preceding the incident. Similarly, the start-up, taxi and incident take-off appeared normal.

The approach, landing and touch-down were also normal. The flight recorders stopped recording when AC power was interrupted about three seconds after touch-down.

Recorders Power Source

The recorders installation has a protection system that is designed to stop recordings automatically on the ground five minutes after the aircraft electrical AC2 system is energised after both engines have been shut down. The CVR and FDR are both connected to the same AC power source and did not have an independent power supply. The recorders thus ceased to record after the aircraft reverted to the emergency electrical configuration following engines shut-down, and denied accident investigators information that could have been vital had the outcome of the landing been different.

Analysis

Operational

The crew reduced the weight of the aircraft and carried out a landing at Gatwick, having planned and configured the aircraft to allow for the possibility of the nose landing gear collapsing on touchdown. In the event a successful landing was carried out. The commander was able to maintain the runway centreline until just before coming to a stop when the aircraft suddenly veered to the left; nevertheless, the aircraft remained on the runway.

Choice of landing field

The crew were familiar with Gatwick Airport and although they at first considered a diversion to Manchester, once they discovered the weather conditions there were less favourable they decided to land at Gatwick. The crew commented that planning and conducting the approach at a familiar airfield reduced their workload considerably.

Approach planning

The crew decided to land at the maximum authorised landing weight as they considered that this was the best compromise between landing in daylight and landing at the lightest weight whilst retaining some fuel reserves. The aircraft was airborne for two hours while the fuel load was reduced, giving the crew plenty of time in which to consider their actions. Had they wished this time could have been reduced by increasing the drag of the aircraft while maintaining the holding pattern, but in fact their only constraint on time was the local time of sunset.

Once the landing gear was successfully extended for the flypast the crew decided to leave it down in case it did not retract normally; this had the added benefit of increasing the rate of fuel burn. From the recorded flight data the fuel burn in level flight before the flypast was around 2,500 kg/hr and with the landing gear extended was 3,600 kg/hr.

Use of QRH procedure

The crew found themselves with an obvious technical problem with the aircraft but one for which there were no ECAM actions or other established procedures. They could not be sure that the existing condition of the nose landing gear would be maintained throughout a landing roll. They considered the various consequences of the other nose wheel coming off on touchdown and/or the nose landing gear strut contacting the runway, and decided to prepare for a possible collapse of the nose landing gear. The most appropriate procedure they were able to find to deal with this was the 'LDG WITH ABNORMAL L/G' procedure from the QRH. They reviewed this procedure and decided how they would conduct the landing, in particular that the engines would be shutdown over the threshold before touchdown. At a later stage they did obtain some further information, for example that one nose wheel was still in place, but did not see any reason to change the original plan.

Presentation of QRH

The QRH procedure has a number of either/or options which are identified by a black dot, for example 'PREPARATION' (Figure 2) contains an option for NOSE or MAIN L/G abnormal. Within the option there may be subheadings, indicated by a short black line. Once the option has been completed the common part of the procedure continues, either at the next short black line for example -OXYGEN CREW SUPPLY or alternatively, in some cases at a boxed heading, APPROACH. The definition between part of an option and the resumption of the common procedure can easily be confused with this method leading to inappropriate actions being carried out. In this case the crew correctly actioned the procedure with the exception that they applied the 'GROUND SPOILERS.............DO NOT ARM' procedure from the main landing gear abnormal subsection (Figure 2).

Despite having plenty of time to review the procedures, including the expanded version from the FCOM, and being reasonably experienced on the type, it is possible that the crew did not appreciate the full intent of some elements. In particular the intention of the amendments to earlier versions of the QRH was for the engines not to be shutdown at least until touchdown, and in the case of the nose landing gear, not until just before nose touchdown. That this was not understood was felt to be indicative of a less than optimal presentation of the procedure rather than any lack of attention by the crew.

The crew action of shutting down the engines before touchdown left the aircraft on emergency electrical power, which deprived them of significant systems and retardation devices, causing a long landing roll with a reduced directional control capability. A possible option, which could have provided electrical power through the landing roll, would have been to have run the APU, but this did not feature in the QRH and its use was not considered by the crew.

Landing performance

The aircraft landed in a degraded status leading to a long landing roll with limited retardation and directional control being available. In fact the actual stopping distance was very close to that provided by the QRH for loss of the green and yellow hydraulic systems (accumulator braking only). Had the engine shutdown been delayed until after touchdown the stopping distance and time would have been reduced.

Engineering Analysis

Both nose wheels, complete with bearings, were fitted to the aircraft at the same time. However, whilst the water content in the grease in the outer bearings on both wheels was similar, the right wheel bearings were assessed as being serviceable and fit for further use. The condition of the inner cup on the left nose wheel indicates that the inner bearing was also serviceable. The damage to the left outer nose wheel bearing roller large end and rib face indicates that the initiating action was roller end scoring. As the roller end scoring developed, friction between the roller large end and rib would cause the rollers to start to skew, forcing the cage upwards between the rollers and cup race. The increased friction between the rib and roller large end, the skewed rollers and the contact between the cage and cup race would combine to increase the torque significantly across the bearing. This would also increase the axial load into the adjacent seal case and nose wheel securing nut. The resulting increased torque and axial force would have been sufficient to cause the interfaces between the cone back face, seal case and securing nut to fuse together. This enabled the torque from the rotating wheel to be transferred to the securing nut causing the two locking bolts to shear and the securing nut to unwind from the axle. The localised signs of overheating suggest that this sequence of events occurred over a relatively short period of time.

Roller end scoring could have been initiated by excessive bearing end load or a break down in the lubrication film. There is no evidence that excessive torque was applied when the wheel and bearing were fitted to the aircraft. The high water content in the grease and the research previously undertaken by QinetiQ suggests that the most likely cause of the failure of the nose wheel bearing was a break down in the lubrication film. Consideration was given as to how the water entered the bearings. The operator's maintenance organisation hand-wash the undercarriage and have a procedure in place to ensure that pressurised water is not applied to the wheel areas; moreover, none of the wheels sampled from six of the other aircraft in the operator's fleet had excessively high levels of water in the grease. The handling and storage of the wheel was also considered, but there was no obvious means by which the bearing could have become contaminated with water. Whilst the washing and handling process can not be discounted, it seems unlikely that this was the source of the water contamination. However, the aircraft had been operating to several European destinations during a particular wet period and it is possible that it was during this period that the bearing grease was contaminated with water.

Whilst the number of bearing failures on the A320 fleet is relatively small, the loss of a wheel during takeoff and landing has the potential to present an immediate danger to other aircraft and ground personnel. Moreover, landing and taking off with one nose wheel increases the chance of the aircraft departing the runway during the ground roll. A number of modifications have been made to improve the integrity of the nose wheel assembly; however, subsequent incidents of nose wheels coming off in flight suggest that the modifications have not been entirely successful. This incident also appears to be the first occasion when high water content in the grease has been attributed to causing the failure of an A320 nose wheel bearing. Whilst the wheel manufacturer has introduced an improved seal, its ability to prevent the ingress of water has yet to be determined, though the manufacturer does believe that it will better at preventing grease from leaking out of the bearing. Whilst there was evidence of some grease having washed out of the bearing, it was assessed that there was still sufficient grease in the bearing to allow it to function normally. It is considered that further investigation into the failure of the nose wheel bearings on the A320 series of aircraft is required and, therefore, the following safety recommendations are made:

Safety Recommendation 2005-072

The European Aviation Safety Agency should ensure that Airbus undertakes a further investigation into the failure of the nose wheel bearings on the A319/320/321 series of aircraft.

Safety Recommendation 2005-073

The European Aviation Safety Agency should ensure that the preventive measures identified by Airbus are introduced into the A319/320/321 series of aircraft to a timescale commensurate with the risk.

Performance specification for flight recorders

The European Organisation for Civil Aircraft Equipment document ED-112, Minimum Operational Performance Specification for Crash Protected Airborne Recorder

Systems, addresses the issues surrounding continuation of recording in the event of power interruptions. In most modern aircraft, the FDR monitors data through the aircraft data busses. If power to a particular sensor is lost, then FDR information related to that parameter will also be lost. Additionally, if power is lost to the avionics controlling the data busses, every parameter transmitted on that bus will be lost. Thus, to continue recording flight data parameters in the event of a power interruption, many avionics systems will be required to continue to be powered and operate in addition to the FDR itself. This contrasts with the requirements to continue the audio recording from an area microphone which is itself solely powered from the CVR. ED-112 thus specified that, as a minimum, the CVR and cockpit area microphone should continue to be powered for short periods regardless of the availability of normal aircraft electric power. In an enhancement to previous specifications, ED-112 added the requirement (and minimum performance specification) for a 10 minute Recorder Independent Power Supply (RIPS) for the CVR and cockpit area microphone.

Previous instances of premature recording cessation

There have been other previous instances of loss of CVR and FDR data due to interruption of power supply to the flight recorders, including, for example, the Transportation Safety Board of Canada' (TSBC) investigation into the Swissair Flight 111 in-flight fire and loss-of-control accident that occurred of the Nova Scotia coast on 2 September 1988. As a result of that investigation, on 9 March 1999 the TSBC issued a recommendation that:

> *"As of 1 January 2005, for all aircraft equipped with a CVR capable of recording for at least 2 hours a dedicated independent power supply be required to be installed adjacent or integral to the CVR to power the CVR and the cockpit area microphone for a period of 10 minutes whenever the normal power sources to the CVR are interrupted"*

In the same report, TSBC made a further recommendation that:

> *"Aircraft required to have two flight recorders be required to have these recorders powered from separate generator busses"*

In response to the above recommendations, Transport Canada supported the latter recommendation, provided that the Canadian regulations and those of the USA were harmonised.

Developments in CVR and FDR Regulations in the USA

In response to the concerns of accident investigators, the regulations regarding flight recorders have been reviewed and, in the USA, new proposals have been promulgated.

The Federal Aviation Authority (FAA) has published proposed revisions to the regulations related to CVRs and digital FDRs in a document titled "14 CFR part 23, 25 et al. Revisions to Cockpit Voice Recorder and Digital Flight Data Recorder Regulations: Proposed Rule" dated 28 Feb 2005. The document quoted additional accidents where the loss of critical flight and cockpit voice data had hampered the investigations. The changes include proposals to improve the reliability of the power supply to both the CVR and FDR and increase the potential for retaining important information needed during accident or incident investigation.

In summary, the document proposes, amongst other improvements, that, for newly manufactured aircraft required to be fitted with a CVR, the installation includes an independent 10 minute back-up power source for the CVR in the event that normal power to the CVR is interrupted. For aircraft required to be fitted with a CVR and an FDR, the document additionally proposes that, for newly manufactured aircraft, the recorders should be powered from the supply calculated to provide the maximum reliability and that a single supply failure should not result in the disabling of both CVR and FDR. There is an additional, proposed requirement for the CVR to operate continuously from the initiation of the checklist before starting the engines for the purpose of flight until completion of the checklist at the termination of the flight. Aircraft would have to comply with these requirements within defined time periods from the acceptance of the proposal, depending upon whether they were of new manufacture or already in service. It is noted that the European Aviation Safety Agency already addresses the need for reliable flight recorder power supplies within Certification Specification CS 25.1457 and CS 25.1459, but does not provide requirements with regard to separation of CVR and FDR power sources.

In the case of the incident to G-BXKD, the landing was carried out successfully with minimal damage to the aircraft. However, had the damage to the aircraft been more severe (for example if the noseleg had been compromised when the wheel fell from the aircraft), then the information that would have been provided by the CVR and FDR could have been vital. For this reason, and to harmonise European regulations with the intent of the FAA, the following safety recommendations are made:

Safety Recommendation 2005-074

For newly manufactured aircraft, the European Aviation Safety Agency should require that no single electrical bus failure terminates the recording on both cockpit voice recorder and flight data recorder.

Safety Recommendation 2005-075

For newly manufactured aircraft, the Joint Airworthiness Authorities should require that the cockpit voice recorder and cockpit area microphone are provided with an independent 10 minute back-up power source, to which the cockpit voice recorder and cockpit area microphone are switched automatically, in the event that normal power is interrupted.