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COMMERCIAL AIR TRANSPORT

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None

ADDENDA and CORRECTIONS

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(ALL TIMES IN THIS BULLETIN ARE UTC)

ACCIDENT

Aircraft Type and Registration:	Airbus A321-211, G-DHJH
No & Type of Engines:	2 CFM56-5B3/P turbofan engines
Year of Manufacture:	2000
Date & Time (UTC):	18 July 2008 at 2010 hrs
Location:	Manchester Airport
Type of Flight:	Commercial Air Transport (Passenger)
Persons on Board:	Crew - 9 Passengers - 219
Injuries:	Crew - None Passengers - None
Nature of Damage:	Crack observed in wing gear rib lug.
Commander's Licence:	Airline Transport Pilot's Licence with Type Rating Instructor and Type Rating Examiner qualifications
Commander's Age:	51 years
Commander's Flying Experience:	12,200 hours Last 90 days - 124 hours Last 28 days - 56 hours
Information Source:	AAIB Field Investigation

Synopsis

During a landing at Manchester Airport the aircraft was not flared sufficiently and a 'hard' landing, categorised as 'severe hard', occurred. The possibility of a landing parameter exceedence was not reported by the crew following discussion with ground engineers who had been on the flight. The presence of a landing parameter exceedence report was identified after a further two sectors had been flown, when an unrelated inspection of the landing gear found a crack in a wing rib gear support lug. Four Safety Recommendations have been made.

History of the flight

The crew reported to fly two sectors, Manchester to Ibiza and return, on an A321 aircraft. The flight crew consisted of three pilots; a training captain who occupied the left flight deck seat and was the commander, a co-pilot undertaking the first two sectors of line training who occupied the right flight deck seat, and another first officer who occupied a flight deck jump seat[1].

The commander read the co-pilot's training file before the flight crew made their way to the aircraft. The co-pilot had recently completed base training on an

Footnote

[1] The company rostered an additional first officer for the first two sectors of every pilot's line training.

A320 aircraft. When interviewed after the accident, the commander's interpretation of the co-pilot's file was that he "had had difficulty landing the aeroplane and had had to have extra landings".

The commander decided that the co-pilot should be pilot flying on the sector to Ibiza. During the flight the commander covered some training items and briefed the co-pilot about the landing. He spoke about the differences between the landing and those during base training, notably that the aircraft was larger and heavier, and he explained that the landing technique for the A321 was different from the A320. The commander instructed the co-pilot that he would "talk him through" the landing and specifically that he would instruct him to "check" the rate of descent with a nose-up sidestick input at 20 ft above touchdown. This would involve selecting 5°of positive pitch attitude and looking outside at the attitude, while simultaneously retarding the thrust levers.

The co-pilot flew a visual circuit onto the final approach to Runway 06 in good weather with a light wind. The landing was "firm", and during the turn-around, the co-pilot identified that he had flared too late. The commander decided that he would fly the aircraft back towards Manchester but would hand control to the co-pilot for the final approach and landing. He briefed that he would, again, talk the co-pilot through the landing and that the co-pilot should look out of the window and learn the visual picture of the landing attitude of the aeroplane. He briefed the co-pilot once again that he would instruct him to "check" on the sidestick at 20 ft, hold the attitude and simultaneously retard the thrust levers.

The flight towards Manchester progressed normally and the commander prepared the aircraft for a flap FULL landing on Runway 23R, adjusting the approach speed in the FMGS to ensure a five knot margin above V_{LS}. The weather at Manchester was good with the 1950 hrs observation indicating that the wind was 180°/5 kt.

At approximately 8 nm from touchdown, the commander handed control to the co-pilot. The co-pilot disconnected the autopilot at 1,200 ft and left the autothrust engaged. The commander watched the co-pilot's sidestick inputs and recalled that he was "over-active" on the sidestick. He stated that he perceived this to be a common problem with pilots transitioning onto the Airbus aircraft.

At 1,000 ft, the commander noted that the operator's stable approach parameters were satisfied and stated "stable A321" in accordance with the operator's SOPs.

The commander gave a coaching narrative during the final moments before touchdown but, as the co-pilot closed the thrust levers, realised that the landing was "going to go wrong". The aircraft touched down firmly and bounced. The commander stated that he considered taking control, but noted that the co-pilot appeared to be holding the aircraft's attitude and that intervention was not necessary. Although the commander believed that he made no sidestick input, FDR data showed that he did move it slightly. After the second touchdown, the landing progressed normally. The co-pilot taxied the aircraft to its parking stand and disembarkation took place.

The commander and co-pilot discussed the landing and both considered it not to have been "heavy". The commander asked some company line engineers, who had travelled back from Ibiza as passengers, for their opinions of the landing and specifically whether they thought it was a 'hard' landing. They replied that if no "load 15 report" had been produced on the flight deck printer and the commander did not consider the landing to have been "heavy", then in their opinion, no action needed to be taken. The commander was unfamiliar with this "load 15 report" (though he knew that the aircraft was capable of printing a report after a heavy landing), but confirmed that no report had been printed.

The flight crew returned to the crew room and discussed the landing. The commander wrote in the co-pilot's training file that he had made a:

> *'good start to line training. Good outbound sector as PF – excellent visual circuit at Ibiza but when thrust retarded for landing, forgot to flare giving hard landing. [The co-pilot] was fully aware of the reason during debrief. PNF inbound, but PF for landing. Another even firmer landing, tried to watch what [the co-pilot] is doing with the sidestick but failed! Perhaps need a demo and talking through again…'*

The commander gave an overall assessment of the co-pilot's progress as 'below target' and telephoned the training captain who was due to conduct the co-pilot's next flight, to brief him on the events.

The co-pilot recalled that darkness was setting in as he landed[2] and commented that he might have touched down on 'the hump' of the runway; he suggested that these factors may have contributed to the hard landing.

The co-pilot

The co-pilot began flying training in 2000 on an integrated course towards a 'frozen' ATPL. Following successful completion of the course, he worked as a flying instructor until 2004 when he was employed by the operator of G-DHJH as a co-pilot on the Boeing 757 aircraft. He operated the Boeing 757 throughout the operator's worldwide route structure until winter 2007/8, when he spent five months flying the Boeing 757 in Canada under a contract arranged by the operator. By the end of this contract, he had 3,500 hrs total flying time, of which approximately 3,000 were on the Boeing 757.

The co-pilot volunteered to convert to the Airbus aircraft and undertook ground school and full flight simulator training during May and June 2008. In early July 2008, he completed base training in the A320 aircraft with CFM56 engines at Prestwick, before commencing line training on the day of the accident. The report on his base training stated that he:

> *'…quickly settled down to fly some nice circuits. Tendency to be slightly late on the flare on 2 occasions so an extra landing was given. This final landing was very good. Overall good standard for base training…'*

The co-pilot described the landing technique learnt during simulator training. He stated that at the 'thirty' automatic voice call, he would commence the flare and retard the thrust levers. He also stated that he was "confused" by the commander's coaching during the landing.

The co-pilot's subsequent training

The day after the accident flight, and before the event had come to light, the co-pilot operated another line training flight with the training captain who had conducted his base training. The co-pilot flew the aircraft to Menorca (Mahon), where he carried out a good landing with "minimal" coaching. The commander flew the aircraft back to Manchester where the co-pilot took control on the approach and made another good landing without coaching. This training

Footnote

2 Sunset was at 2026 hrs, 16 minutes after the landing.

captain commented that the co-pilot's technique was *'perfectly correct'* and that both touchdowns were smooth and accurate.

The co-pilot's training continued after the accident flight, and he received eight sectors of line training, followed by a successful two-sector line release check. The relevant training report stated he flew *'to a good standard'*.

The commander's sidestick technique while training

The commander during the accident flight stated that when training, his custom during the landing phase was to keep his left hand on the sidestick, with his palm touching the sidestick. He added that he was "very wary" of making an involuntary sidestick input while training on the aircraft, and that he would not do so without operating the takeover pushbutton. Previous investigations have revealed that occasionally Airbus training pilots make surreptitious sidestick inputs when training new pilots, applying nose-up pitch just before touchdown to ensure a reasonable landing. The commander stated that this was not his practice.

Manufacturer's instruction

The Standard Operating Procedures contained in the Airbus Flight Crew Operating Manual (FCOM) issued to flight crew by the operator, included the recommended landing procedure, shown in Figure 1.

In comparison, the advice with regard to A321 aircraft is shown in Figure 2.

The Flight Crew Training Manual (FCTM) for the aircraft, which the company suggested was mainly used as guidance for training staff, (although line pilots would be expected to have some knowledge of its contents), stated:

'PITCH CONTROL

'When reaching 50 ft, auto-trim ceases and the pitch law is modified to flare law. Indeed, the normal pitch law, which provides trajectory stability, is not the best adapted to the flare manoeuvre. The system memorizes the attitude at 50 ft, and that attitude becomes the initial reference for pitch attitude control. As the aircraft descends through 30 ft, the system begins to reduce the pitch attitude at a predetermined rate of 2 ° down in 8 s. Consequently, as the speed reduces, the pilot will have to move the stick rearwards to maintain a constant path. The flare technique is thus very conventional.

From stabilized conditions, the flare height is about 30 ft. This height varies with different parameters, such as weight, rate of descent, wind variations...

Avoid under flaring.

- *The rate of descent must be controlled prior to the initiation of the flare (rate not increasing)*
- *Start the flare with positive backpressure on the sidestick and holding as necessary*
- *Avoid forward stick movement once Flare initiated (releasing back-pressure is acceptable)*

At 20 ft, the "RETARD" auto call-out reminds the pilot to retard thrust levers. It is a reminder rather than an order. The pilot will retard the thrust levers when best adapted e.g. if high and fast on the final path the pilot will retard earlier. In order to assess the rate of descent in the flare, and the aircraft position relative to the ground,

- **At 30 feet approximately (A330: 40 feet)**

- **FLARE…………….. .... PERFORM**

- **ATTITUDE………………………………………………………………….MONITOR**
  The PNF's primary responsibility in this critical phase of flight is to ensure that the correct pitch attitude is achieved thereby avoiding a tailstrike. The PNF should continuously monitor the attitude until nosewheel touchdown and call out:

  "PITCH, PITCH" if the pitch angle reaches -2.5º or +7.5º (A320/1)
  "PITCH, PITCH" if the pitch angle reaches 0º or +7.5º (A330)
  "BANK, BANK" if the bank angle reaches 7º

- **THRUST levers..IDLE**

  In manual landing conditions, the call out "RETARD" is generated at 20 feet RA as a reminder. Commence a gentle progressive flare and allow the aircraft to touch down without prolonged float. If the thrust levers are not retarded when the flare is started, the AT will remain in SPEED mode. The thrust will increase in order to maintain Vapp, which could result in prolonged float.

  Be aware of a tendency for the nose to pitch up slightly at spoiler deployment.

Figure 1

If you handle the A321 correctly in the landing phase, a tail strike will not occur. Correct handling includes:

1. Flying a stable approach and not chasing the PAPIs or Glideslope below 200'.
2. Ensuring you have a 5kt buffer between VLS and Vapp on the PFD on approach.
3.. On landing, not holding any back sidestick and being prepared to counteract any pitch up by flying the nose onto the runway

Please note that the SOP on approach <u>on the A321 only</u> is to check that there is at least a 5kt gap between VLS and Vapp and, if necessary, to overwrite Vapp on the MCDU to ensure that this is the case.

Further information is in FCOM Bulletin 806/1 and 819/1.

Figure 2

look well ahead of the aircraft. The typical pitch increment in the flare is approximately 4°, which leads to -1° flight path angle associated with a 10 kt speed decay in the manoeuvre. A prolonged float will increase both the landing distance and the risk of tail strike.'

Recorded data

The aircraft performed two further flights prior to the incident being reported to the AAIB and consequently the CVR was overwritten. Flight data was recovered from the operator's Flight Data Monitoring (FDM) programme and used to analyse the approach and landing in Manchester.

The data showed G-DHJH established on the ILS for Runway 23R at Manchester with the autopilot and autothrottle engaged and landing gear, flaps and slats fully extended. At 1,200 ft, the autopilot was disconnected and flight control inputs for the rest of the approach were controlled using the co-pilot's sidestick. The autothrottle remained engaged until touchdown.

Relevant flight parameters during the final stages of the approach and landing at Manchester are shown in Figure 3. The data starts with G-DHJH approximately 2.2 nm from the Runway 23R threshold at a radio altitude of 584 ft, indicated airspeed of 147 kt and calculated rate of descent[3] of approximately 750 feet per minute (ft/min). The airspeed, which had progressively decreased during the descent, was 2 kt above V_{APP} with a recorded wind speed of 218°/11 kt.

At a radio altitude of 42 ft, the co-pilot initiated a pitch-up demand on the sidestick. At the same time, the aircraft began drifting below the glideslope, achieving maximum deviation one second after the pitch up command.

Just less than one second later, the aircraft pitch began to increase from approximately 1° nose up, at a rate of approximately 2° per second. At the same time, the throttle levers were retarded to idle. One second from touchdown, the aircraft was at 15 ft radio altitude and a derived rate of descent of approximately 900 ft/min (15 ft per second (ft/s)).

The recorded position of the co-pilot's sidestick showed a continued stick-back command, to the maximum achievable position of 16°. This full back position was recorded at the same time as the initial spike in normal acceleration, signifying aircraft touchdown. Indicated airspeed was 145 kt, pitch attitude 3.9° and derived rate of descent was approximately 840 ft/min (14 ft/s). Rate of descent is approximate due to the one second sampling rate of the radio altitude.

After the initial spike in normal acceleration, the data shows a peak of 2.66g, a quarter of a second later. The initial spike prior to the maximum may have been due to one main landing gear touching down prior to the other (roll attitude was 0.7° left wing down). Both the left and right landing gear squat switches registered weight on wheels at the same time but these parameters are sampled every second so would not register a difference in touchdown time of the left and right gear of less than one second.

Just after touchdown, the commander applied 2° of forward and 4.3º of right sidestick. The normal acceleration then decreased to less than 1g which is indicative of a bounce but the MLG squat switches did not register weight off wheels. Pitch attitude reduced and three seconds after main gear the nose landing gear touched down.

Footnote

3 Rate of descent was not recorded but has been calculated from the rate of change of radio altitude.

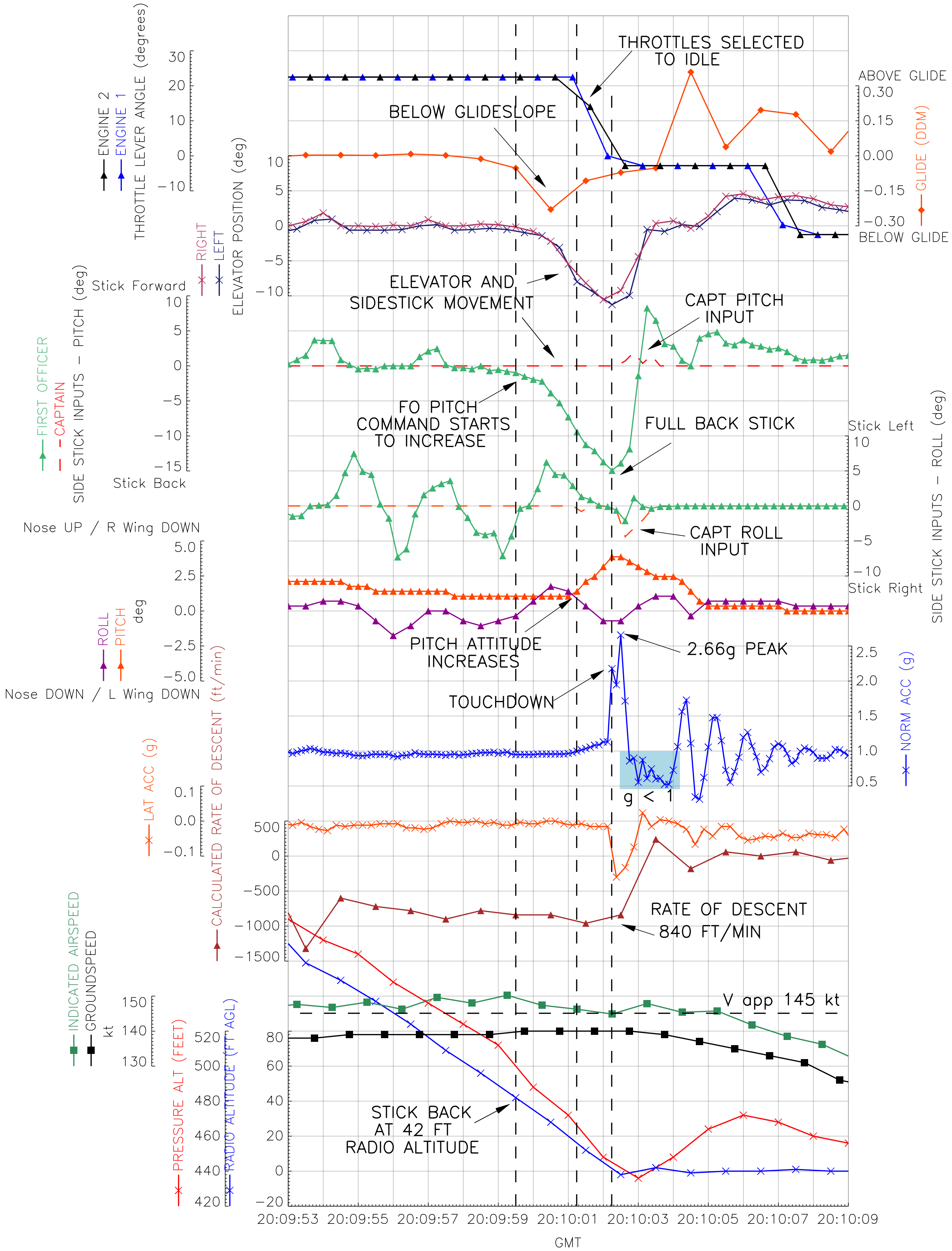

Figure 3

G-DHJH landing in Manchester, 18 July 2008

Training in Airbus fly-by-wire aircraft

Manual control inputs in the Airbus fly-by-wire aircraft are made through sidestick controllers. One sidestick is located on each outboard side of the flight deck. The sidestick positions do not reflect the positions of the flying control surfaces. Whereas traditional control columns are mechanically linked so that they move in synchronisation regardless of whether an input is made by the left or right seat pilot, the sidesticks do not.

The commander commented that although he realised that the landing was not going to be normal, he was aware that it was impossible to "watch the sidestick all the time". He stated that he "always liked to try", but "usually failed" to watch the sidestick inputs effectively, because he "liked to see what was going on outside".

Landing technique: A320 and A321 aircraft

The commander stated that in his opinion, the A320 and A321 aircraft required different landing techniques and that further differences in technique were necessary to take account of the engines fitted to the aircraft[4]. He mentioned that although the Airbus FCOM stated that the flare and retardation of the thrust levers should take place at 30 ft, the operator's training pilots "think that's too high" in an A321. He also stated the A321's used by this operator are operated at significantly higher weights than those operated in a scheduled service configuration.

Another experienced Airbus training captain, with current experience on the A320 and A321 aircraft, considered that the advice about flare heights published in the Airbus FCOM was adequate and that 20 ft would be too late to commence the flare in an A321 aircraft.

The operator's training department clarified with the commander that company policy is to teach the same landing techniques for both the A320 and A321 aircraft.

Post-flight events and aircraft examination

Given that no technical log entry or air safety report had been raised by the crew following the 'firm' landing event into Manchester, the aircraft was released for service as normal and operated a further two sectors without reported incident.

The operator used an electronic tech log system for the aircraft, which had been unavailable for a period of time prior to this point. It became available for use on the proposed next sector but when consulted, it warned that a mandatory out of phase inspection had become overdue on the aircraft. The aircraft was grounded until this inspection could be completed. It was later determined that the inspection was only *due* rather than *overdue*, as issues with the software of the tech log result in any aborted flight and return to stand still being counted as a full flight cycle. This problem is due to be rectified in a new software standard.

The mandatory inspection was a visual check for cracking on the main landing gear pintle support lugs which are part of wing rib 5. The inspection is mandated by EASA Airworthiness Directive (AD) 2007-0213 and is carried out in accordance with Airbus Service Bulletin A320-57-1138. When the inspection took place on 22 July 2008, it identified that the left pintle support rib had a crack extending through the entire section of the forward lug (Figure 4) and had to be replaced prior to further flight.

It appears that the operator was aware of the suspected 'heavy' landing two sectors previously and concerns were raised that the crack was a consequence of that

Footnote

4 The operator's fleet included A320 and A321 aircraft, with CFM56 and IAE V2500 engines.

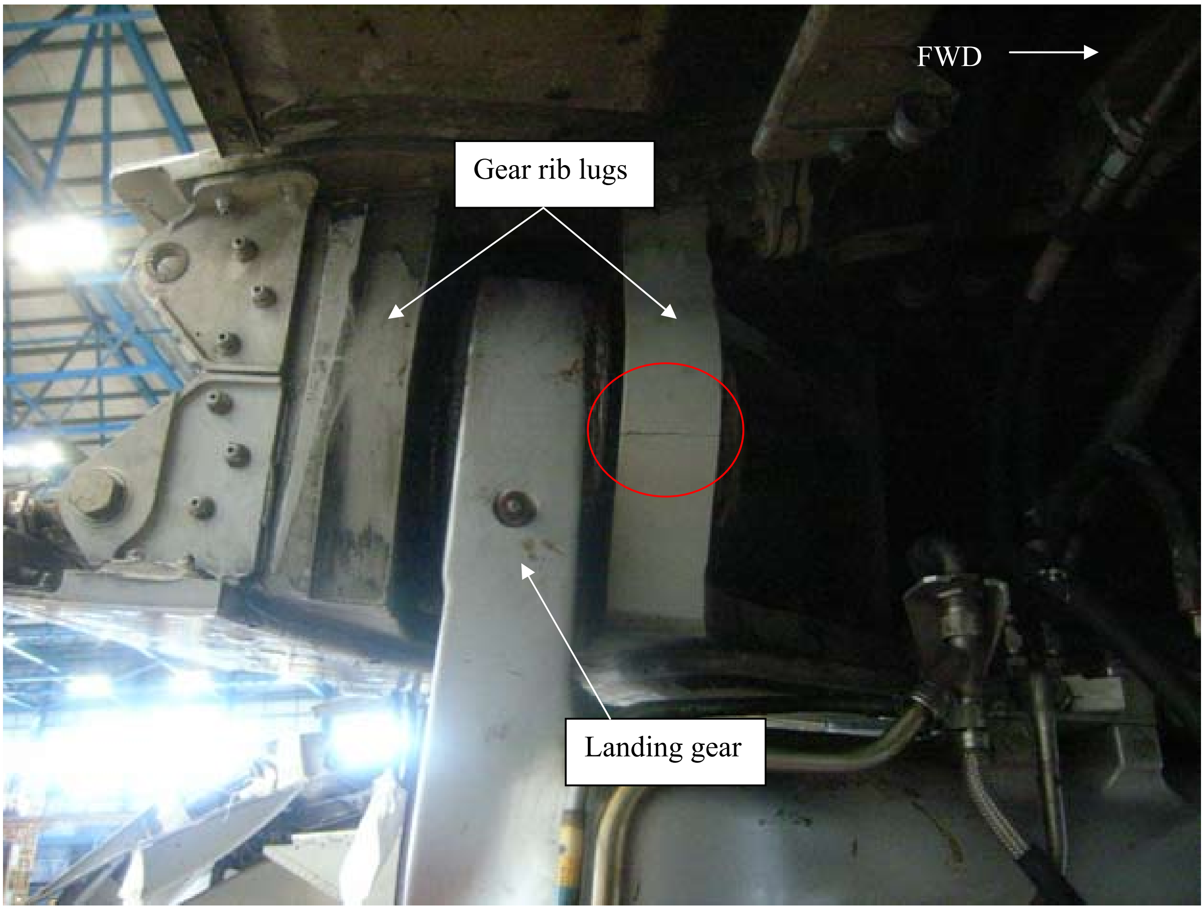

Figure 4

Landing gear support rib with cracked forward lug

landing. Interrogation of the aircraft Data Management Unit (DMU) by engineers confirmed that a LOAD <15> report had been generated. This report recorded vertical acceleration and descent rate exceedences at touchdown during the landing at Manchester on 18 July 2008. The LOAD <15> report gave figures of 2.65g and -11.5 ft/s at touchdown which identified the landing as 'hard' based on maintenance manual limits. Analysis of flight data from that sector identified that the aircraft experienced a vertical acceleration of 2.66g and a rate of descent of 14 ft/s at touchdown. A rate of descent of 14 ft/s classified the landing as 'severe hard' and required the operator to carry out additional, more in-depth inspections of the aircraft. These should have been completed before further flight following the landing but were eventually carried out by the operator while the aircraft was grounded to allow the cracked gear rib to be replaced. Some unrelated corrosion damage in the right wing spar was identified as a result of these inspections, but they confirmed that no damage directly attributable to the severe hard landing had occurred.

LOAD <15> report

The A320 family of aircraft have an Aircraft Integrated Data System (AIDS). This system receives information from many other systems on the aircraft through its DMU. The DMU then processes this data and produces reports based on various parameters, such as an exceedence. One such group of reports is based on structural parameters. The structural report is identified as a LOAD <15> report (Figure 3) and is produced when any of the following landing conditions are met:

1) The radio altimeter descent rate (RALR) is less than (higher rate of descent) -9 ft/sec.

2) The vertical acceleration (VRTA) is more than +2.6G during +/- 0.5 seconds before and after landing.

3) The aircraft gross weight (GW) is more than the maximum landing gross weight (GWL) and the radio altimeter rate (RALR) is less than -6 ft/sec.

4) The aircraft gross weight (GW) is more than the maximum landing gross weight (GWL) and vertical acceleration is more than +1.7G.

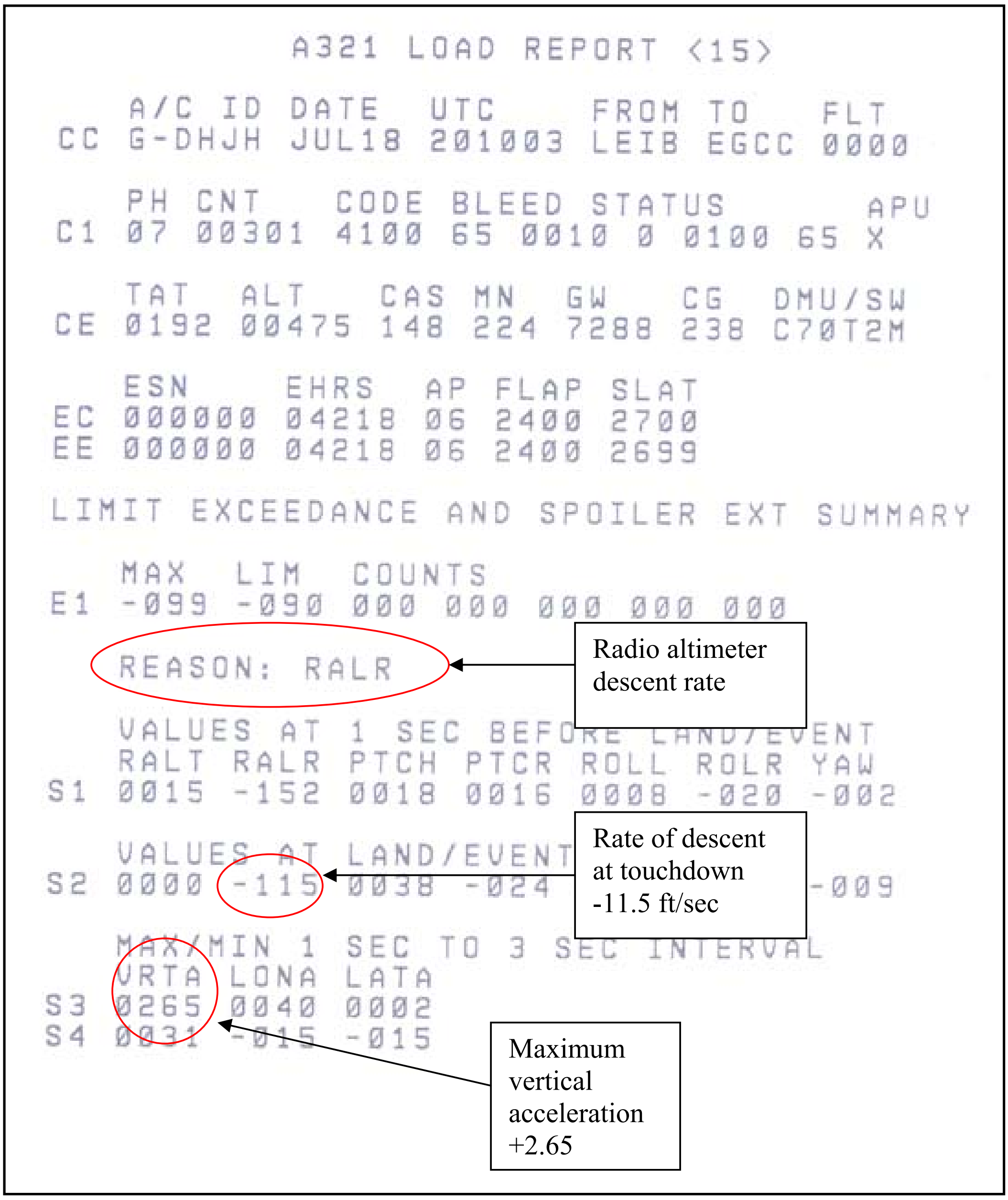

Figure 3

LOAD<15> Report

5) For a bounced landing the vertical acceleration (VRTA) exceeds +2.6G for +/- 0.5 seconds of a detected bounced landing.

The manufacturer offers the option of the DMU automatically printing out the LOAD <15> report at the end of the flight, when one has been generated. However, the unit fitted to this aircraft was not configured to produce this automatic printout and required manual interrogation of the DMU to access the report. The presence of a LOAD<15> report is not highlighted by the Central Fault Display System (CFDS) or the Electronic Centralised Aircraft Monitor (ECAM).

Since this event, the operator has configured all its Airbus aircraft to have the LOAD<15> auto-print facility enabled.

EASA AD 2007-0213

This AD supersedes AD 2006-069R1 which was introduced in response to several incidents of cracked main landing gear support lugs being identified across the A320 family of aircraft in service. The cracks are initiated from corrosion pitting which occurs in the rib forward lug bore when moisture penetrates between the lug and the bushing. The crack will eventually propagate across the entire thickness of the lug, with an associated impact on the structural integrity of the main landing gear installation. The AD provides a choice of repetitive inspection regime depending on whether the inspection is done by ultrasound or visually. The operator involved in this accident had elected to inspect visually and as such was obliged to inspect the lug

> *'within 100 flight cycles following the last inspection as per AD 2006-0069R1'*

until the terminating modification action had been embodied. The AD also places an additional requirement on the operator to inspect the lug

> *'before next flight following a hard landing.'*

Under the visual inspection regime, once a crack of any size has been identified, the rib must be replaced before further flight.

A320/321 Approved Maintenance Manual

The maintenance manual has a specific task reference *'05-51-11-200-004 – inspection after hard/overweight landing for aircraft with enhanced DMU/FDIMU Load Report 15'* to cover the engineering response to a reported hard landing. Paragraph A (2) (a) states that

> *'it is the responsibility of the flight crew to make a report if they think there was a hard/overweight landing.'*

Part (b) states:

> *'after a crew report of a hard/overweight landing, you must confirm the impact parameters to know the category of the landing. To know this, refer to: - the DMU load report 15*[5] *or - the FDRS read out.'*

Once the extent of the parameter exceedence has been identified, the task directs specific inspections to be carried out on the aircraft.

Gear rib 5 failure analysis

The rib was removed from the aircraft by the manufacturer and passed to the AAIB for further

Footnote

[5] The user is referred to AMM Task 31-37-00-200-001 in order to obtain the report.

investigation and analysis. The cracked section of the lug was removed (Figure 6), the fracture faces cleaned and then inspected using a scanning electron microscope. This analysis determined that the crack was caused by fatigue growth initiating from surface corrosion pitting around the edge of the bore (Figure 7). From the staining on the surfaces and oxidation/corrosion damage on the fracture surface, it is likely that the fatigue growth had taken place over a considerable period of time before the final fracture occurred. It was not possible to find sufficient detail to determine exactly how long the fatigue crack had been present but the critical crack length was consistent with previous failures. There is no evidence to suggest that the material was in any way deficient as the microstructure, hardness and conductivity all appeared to be as per specification. The crack was located in the one o'clock position of the lug looking forward. A crack in this location represents a failure of the primary load path for the lug. The secondary load path is via the opposite quadrant of the lug and no cracking was found in this location.

Operational analysis

The operational aspects of this accident stem from the training captain's perceived differences between landing the Airbus A320 and A321 aircraft. According to the manufacturer's FCOM and the complementary FCTM, the same landing technique applies across the A320 family of aircraft[6] but the opinion of the commander was that the A321 required a different technique and

Figure 6

Cracked section of forward lug with the bush removed

Footnote

[6] The A318, 319, 320, and 321.

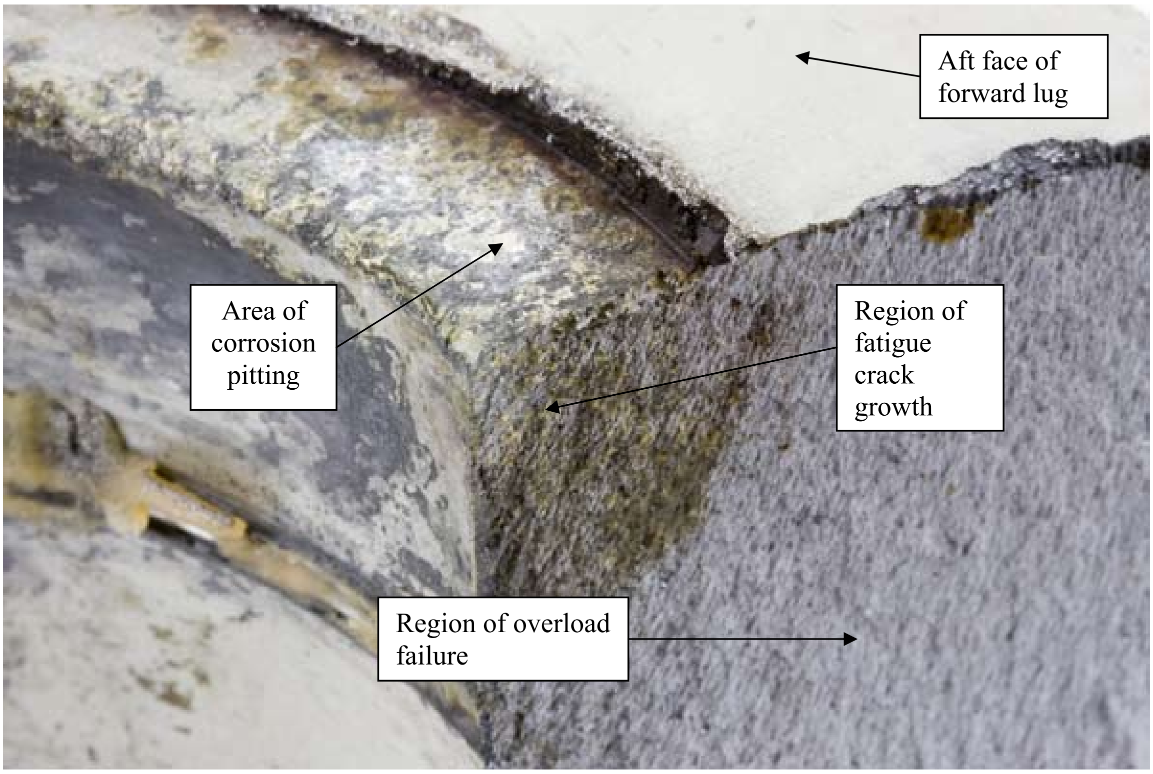

Figure 7

Detailed view of forward lug fracture surface

therefore he considered it necessary to coach the co-pilot through his first landings. The acceptance of the manufacturer's technique by other experienced training pilots and the absence of specific advice or information in the manufacturer's documents, suggest that the same technique is applicable across all variants.

The commander's impression that the co-pilot "had had difficulty landing the aeroplane" during base training was based on the base training report which stated that the co-pilot had a *'Tendency to be slightly late on the flare on 2 occasions'*. This had led to one extra landing being included in the training detail, that final landing being *'very good'* and an *'overall good standard for base training'*. The commander's impression of this report may have influenced him to be more prescriptive in his training technique than would otherwise have been the case.

Following the landing in Ibiza, the training captain discussed the landing with the co-pilot and agreed with his observation that the flare was commenced too late. Analysis of the recorded flight data showed that the co-pilot flared at about the correct time but not at a sufficient rate. Consequently, on the accident flight, the flare was commenced above the Airbus recommended height but still at an insufficient rate of pitch change to reduce the rate of descent significantly prior to touchdown.

Engineering Analysis

After consulting with ground engineers and informally discussing the incident within the airline, the flight crew chose not to report a suspected parameter exceedence formally. The lack of any supporting evidence available at the time, such as an automated printout of a LOAD <15> report, required the crew to make a subjective assessment of the landing. The ground engineers consulted by the flight crew were unaware that a LOAD<15> report would not always be automatically printed and the subsequent lack of even a precautionary tech log entry meant that no process for a formal engineering investigation was initiated. Consequently the DMU was not interrogated and the presence of the LOAD <15> report confirming the hard landing was not identified before the next flight.

Therefore:

Safety Recommendation: 2009-059

It is recommended that Airbus ensure that the generation of a LOAD<15> report by the DMU following a landing parameter exceedence, is indicated to the flight crew involved to enable them to record it in the aircraft's technical log.

Safety Recommendation: 2009-060

It is recommended that the Civil Aviation Authority require operators to provide training in the procedures associated with the reporting of suspected hard landings and the information available to assist decision making on reporting for the aircraft types operated. This should include, for Airbus types, the nature, significance and interpretation of Airbus LOAD<15> reports.

Safety Recommendation: 2009-061

It is recommended that the European Aviation Safety Agency ensure adequate training is provided for ground engineers maintaining Airbus aircraft regarding the correct approach to troubleshooting suspected hard landings and the correct means of obtaining and interpreting the Airbus LOAD<15> report.

The manufacturer's approach to dealing with a hard landing and its associated airworthiness implications requires the flight crew involved to initiate the process. A readily available LOAD<15> report would substantially reduce the subjective element of the flight crew reporting process. A technical log entry by the crew then ensures that further action is instigated.

In this accident, once the presence of the LOAD<15> report was confirmed, the level of parameter exceedence identified that the landing should be classified as 'hard' based on maintenance manual limits. However, analysis of the flight data identified a calculated rate of descent at touchdown higher than that recorded on the LOAD<15> report, resulting in a re-classification of the landing as 'severe hard'. This resulted in more significant inspections being carried out on the aircraft. In order for the two sources of data to correlate, various factors and calculations need to be applied to the raw flight data which are only available within a specialist department of the manufacturer. However, the maintenance manual currently instructs the operator to classify the landing based on either the LOAD<15> report or the flight data readout, without identifying that analysis of the raw flight data is required to give an accurate result. The difference between the DMU and the raw flight data, as occurred in this event, can result in significantly different levels of inspection being required to comply with the maintenance manual. This creates the potential for either an excessive maintenance burden to be placed on the operator, with an associated increase in risk of human factors-type errors or aircraft damage to remain undetected prior to further flight.

Therefore:

Safety Recommendation: 2009-062

It is recommended that Airbus review their procedure for identifying and classifying parameter exceedences based on data recorded by the aircraft during landing, either to ensure that all sources of recorded data give the same outcome or to provide guidance on which source of data should take precedence in the event of a discrepancy. Changes resulting from this review should be reflected in the relevant maintenance manual tasks.

The manufacturer has advised that this issue is intended to be addressed by a planned change in approach to maintenance following a hard/severe hard landing, which will result in an entirely new maintenance manual procedure.

The final overload phase of the lug failure in the gear support rib is likely to have been accelerated by the hard landing, though it was not possible to confirm this from the fracture surfaces. All other characteristics of the crack are consistent with the manufacturer's analysis of previous failures in this location. The mitigating actions already in place under EASA AD 2007-0213 are adequate to ensure the continued airworthiness of the aircraft. However, the effectiveness of the AD is dependent on all inspections being completed at the correct time. This includes the additional inspection following a hard landing.

An investigation into an accident to another aircraft from the same family has drawn similar conclusions relating to the determination and reporting of unusual landings and the subsequent required inspections. The safety recommendations in this report are complimentary to those made in AAIB report EW/C2008/07/05, the text of which is shown below for completeness.

'It is recommended that Airbus includes in the appropriate publications, further information and guidance to flight crew with regard to unusual landings to ensure they are able to properly discharge their responsibilities to declare potential high load events.

It is recommended that Airbus review the landing parameters recorded on any of their aircraft types which are able to produce a LOAD<15> report, so that a LOAD<15> report is generated whenever there is potential for damage to be caused to the aircraft and/or its landing gear following both hard/overweight landings or abnormal landings, such as nosewheel first landings.'

ACCIDENT

Aircraft Type and Registration:	Airbus A321-231, G-MARA
No & Type of Engines:	2 International Aero Engine V2533-A5 turbofan engines
Year of Manufacture:	1999
Date & Time (UTC):	28 July 2008 at 2145 hrs
Location:	Manchester International Airport, Greater Manchester
Type of Flight:	Commercial Air Transport (Passenger)
Persons on Board:	Crew - 8 Passengers - 159
Injuries:	Crew - None Passengers - None
Nature of Damage:	Nose landing gear internal shock absorber assembly severely distorted
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	39 years
Commander's Flying Experience:	6,930 hours (of which 1,545 were on type) Last 90 days - 200 hours Last 28 days - 79 hours
Information Source:	AAIB Field Investigation

Synopsis

The aircraft made a hard landing, in a flat attitude, in which the nose landing gear sustained internal damage. An engineer, following the process in the Aircraft Maintenance Manual (AMM), determined that no inspections were required as the relevant recorded parameters had not exceeded the stated threshold values. On the next flight, the flight crew were unable to retract the landing gear. Subsequent nvestigation of this defect identified internal damage to the nose landing gear and a bent proximity switch link rod. The nose landing gear was replaced and extensive inspections conducted before the aircraft was released to service. Three Safety Recommendations are made.

History of the flight

G-MARA was operating a night charter flight from Malaga to Manchester Airport, with the co-pilot as the pilot flying (PF). The flight had been operated in accordance with company procedures and had been without incident until the landing.

The landing flare was initiated slightly early and the aircraft settled into a 'float' at approximately 10 ft above the runway (radio height). Whilst in the 'float', the co-pilot's sidestick briefly moved to fully forward then to fully aft. The aircraft reacted with a rapid nose-down pitch and touched down in a near flat attitude. A significant bounce occurred, which was controlled by the co-pilot; a second touchdown and rollout ensued.

The commander taxied the aircraft to the parking stand where it was shut down normally.

Three passenger service unit oxygen masks had dropped from their stowages but no other effects of the landing were apparent and no injuries had occurred.

Initial maintenance actions

As the passengers were disembarking, a company ground engineer boarded the aircraft. He spoke to the flight crew, who reported that they informed him the landing had been heavy, and that they were certain some sort of damage must have occurred. The ground engineer later stated that he had understood from this conversation that the aircraft had landed heavily and bounced. Neither party mentioned that they were aware that the nosewheel may have touched down first.

The engineer referred to the relevant part of the AMM, Section 05-51-11-200-004-A, *'Inspection after hard/overweight landing for aircraft with enhanced DMU/FDIMU LOAD <15> report*[1]*'*, to determine his course of action.

Because of the crew report, the engineer expected to see an automatically printed LOAD <15> report but, as there was not one, he accessed the Aircraft Integrated Data System (AIDS) Data Management Unit (DMU) to look for a stored report in the event that it had not printed. The DMU did not contain any such report; consequently, the engineer concluded that the landing could not have been as hard as the crew suspected as none of the DMU parameter limits had been exceeded. Therefore, no inspection was required. However, because of the crew's concerns, he thought it would be prudent to carry out the visual items of the Phase 1 inspection for a heavy landing. This was completed and no damage was identified. The dropped oxygen masks were re-stowed, the technical log entry was cleared with these actions, and the aircraft released back into service.

Later that night, G-MARA departed Manchester but the flight crew were unable to raise the landing gear and received a landing gear shock absorber fault message. The aircraft returned to Manchester and landed without further incident.

Further maintenance activity

Fault finding of this defect initially concentrated on the nose leg proximity sensors. In order to check their operation, the nose of the aircraft was jacked up, but the nose leg did not extend as expected and fluid started leaking from the assembly. Further examination and disassembly identified that the internal shock absorber assembly was severely distorted and a link rod, which connects the upper arm of the torque link to the moving proximity sensor target mounting, was bent.

The aircraft manufacturer was approached by the operator and provided with the data from the Flight Data Recorder (FDR) relating to the landing, to determine the extent of any further inspections they might consider necessary. The nose leg assembly was replaced, but the various additional inspections did not identify any other damage to the aircraft.

Flight Recorders

In accordance with regulatory requirements, the aircraft was equipped with a FDR and a Cockpit Voice Recorder (CVR). The FDR recorded just over 60 hours of data and the CVR 120 minutes of audio[2]. Parameters from

Footnote

1 See paragraph headed *'Automatic LOAD<15> report'*.

Footnote

2 Unlike the FDR, which operates upon engine start and ceases on engine shutdown, the CVR operates whenever the aircraft is electrically powered and so is more susceptible to being overwritten unless prompt action is taken to preserve its record.

the FDR included the position of both the commander's and co-pilot's sidestick, the aircraft pitch attitude, radio altimeter height and normal acceleration, sensed by an accelerometer mounted near to the aircraft's centre of gravity. A time history of the relevant parameters during the final stages of the landing is shown in Figure 1. The aircraft was also equipped with a Quick Access Recorder (QAR), which recorded the same data as that of the FDR onto a removable memory device.

Recorded information

The FDR, CVR and QAR media were removed from the aircraft and successfully replayed. The FDR provided a complete record of both the incident flight and the proceding outbound sector from Manchester. Unfortunately, by the time the severity of damage to the nose gear had been identified, the CVR record relevant to the arrival at Manchester from Malaga, had been overwritten. The QAR data was replayed by the operator.

The aircraft had departed Malaga Airport at 1912 hrs and the flight was uneventful until the later stages of the landing. At 2131 hrs, three minutes before touchdown, the aircraft was stabilised on the ILS approach for Runway 05L at a height of about 1,300 ft and was configured for landing with full flap and the landing gear down and locked. At a height of 1,150 ft, the autopilot was disconnected and the co-pilot took manual control. The autothrust remained engaged for the approach and landing, with the approach speed stabilised between 140 kt and 147 kt. The recorded wind was from an easterly direction and had reduced to less than 15 kt during the final 150 ft of the approach.

The aircraft remained stabilised on the ILS approach and, at a height of about 35 ft, the co-pilot started to flare the aircraft, Figure 1, Point A. The initial part of the flare appeared normal, with the thrust levers being retarded and the aircraft pitch attitude being stabilised at about 4° nose-up; roll attitude was wings level and the airspeed was 135 kt. As the aircraft closed to within about 10 ft of the runway, the co-pilot's sidestick was moved rapidly to the fully forward position, before moving to the fully aft position, Figure 1, Point B. The aircraft responded, de-rotating rapidly at 4.5°/second before touching down at a pitch attitude of about 1° nose down, Figure 1, Point C. A peak normal acceleration of 1.99g was recorded as both the nose and right main gear oleos compressed within one second of each other; the left main gear oleo compressed less than a second later. The aircraft then bounced, indicated by the extension of both main gear oleos and change in normal acceleration to less than 1g. The aircraft remained airborne for just over a second, during which the co-pilot attempted to reduce the aircraft sink rate by applying full aft sidestick and advancing the thrust levers; however, the aircraft touched down on the main gear with a normal acceleration of 2g. The thrust levers were then fully retarded. The spoilers had deployed automatically on landing and reverse thrust and manual wheel braking were applied. There had been no movement of the commander's sidestick during the entire approach and landing phase. Aircraft gross weight at touchdown was 63,133 kg.

Following the initial bounced landing, the aircraft had pitched to 6° nose up and both main gear oleos extended. However, the nose landing gear indicated that it was still compressed, when it could not have been in contact with the ground. Subsequent analysis of the FDR data confirmed that none of the LOAD <15> report limits had been exceeded. At a landing weight of 63,133 kg, a LOAD <15> report would have been triggered if the radio altimeter-derived descent rate and normal acceleration limits of 9 ft/sec and 2.6g had been exceeded. At the initial touchdown, these parameters were recorded as 3 ft/sec and 2g respectively.

During the taxi for departure at Malaga, a full-and-free check of the primary flight controls was made; both the commander's and co-pilot's sidesticks were operated through their full range of movement, with no evidence of any abnormalities being recorded. The performance of the aircraft was also analysed, in conjunction with the aircraft manufacturer. During the flare it was found to have responded normally to the recorded movement of the co-pilot's sidestick. There were no reports from the operator of any defects associated with the co-pilot's sidestick, either before or after the accident.

Co-pilot's training

The co-pilot had commenced commercial jet operations in August 2005, when he started flying the 737-500 aircraft. In February 2008, he began line flying the Airbus A320 series and had accrued 248 hours on type at the time of the accident. During type conversion training, he had found the conventional hand position on the sidestick uncomfortable to use and, at the suggestion of a training captain, he began using a different 'grip', much lower on the sidestick.

A review of landings conducted by the co-pilot was carried out using stored flight data.

- On the 30 June, the commander took control from the co-pilot following a 1.83g touchdown
- On the 5 July, a high de-rotation event of a similar nature to the accident flight occurred, but with no resultant damage to the aircraft
- On the 16 and 17 July, high de-rotation events had occurred, although resulting from different sidestick inputs from that on G-MARA

Following the accident to G-MARA, the operator conducted additional simulator, base and line training with the co-pilot. No issues were found during this training and he was cleared to resume line flying. Subsequently, a review of his landings was conducted using OFDM data, to validate the training, and no issues with his ability to land the aircraft were discovered.

Sidestick issues

Information was sought from the manufacturer about the 'design' hand position for the sidestick controller. They commented that the intended method of use of the sidestick is:

'- *Use the armrest at all times and memorise the letter and digit which gives the more comfortable position when found and confirmed.*

- *The side stick has an ergonomic design. It has on its top a hollow for the thumb rest. The normal use is to grasp the stick, rest the thumb in the hollow being ready to press the takeover push button when needed. The index finger is used to press the trigger to talk.*

The side stick should be used carefully by giving slight inputs to avoid the large pitch or bank variations.'

During the investigation, pilots from a range of operators were asked how they grip the sidestick. There appeared little consensus from their comments, other than that many pilots do not hold the sidestick in the manor intended by the manufacturer. The nature of the fly-by-wire flight control software is such that a 'bump and release' technique appears common when flying manually. This lends itself to a much looser 'two fingered grip than when flying a

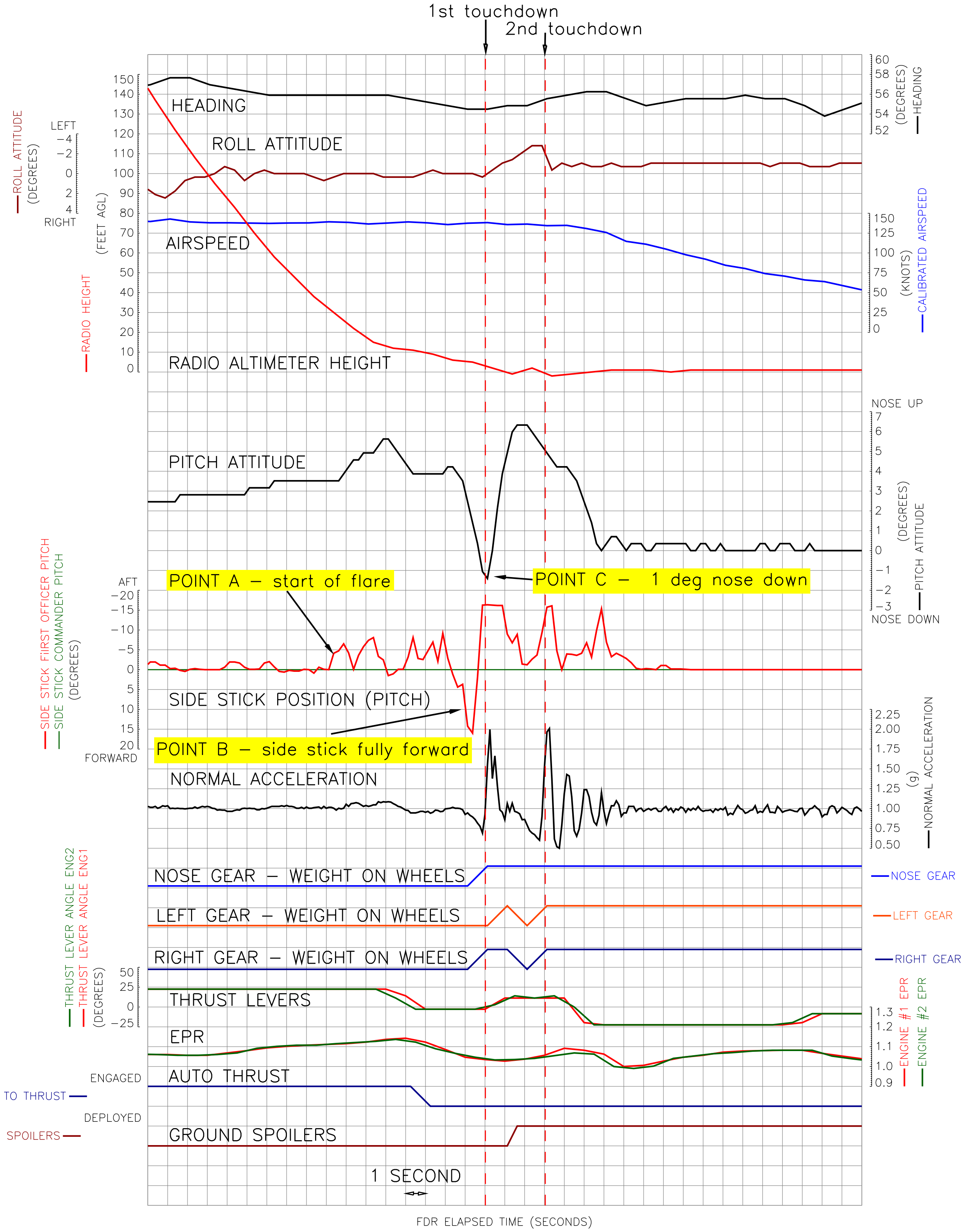

Figure 1

Salient FDR Parameters
(Incident to G-MARA on 28 July 2008)

conventionally controlled aircraft. The takeover button and radio trigger are located on the sidestick such as to require minimal movement of the hand when using the manufacturers intended grip position. Alternative grip techniques may compromise the pilot's ability to operate these buttons simultaneously.

Heavy landing determination

Many commercial transport aircraft have no immediately accessible instrumentation for the flight crew to determine normal acceleration during landings. As such, it is incumbent on the flight crew to report heavy landings. The assessment of the severity of a heavy landing is therefore highly subjective.

The A320 series of aircraft are fitted with a system that will sense when landing parameters, including normal acceleration, have been exceeded, and will generate a LOAD<15>report, following which inspection of the aircraft for damage is required (see paragraph headed '*Automatic Load<15> report*'). Where instrumented limits are set, the various aircraft manufacturers use different acceleration limits for defining such landings where, mostly, the normal acceleration is sensed close to the aircraft's centre of gravity position. In this case, the pilots were convinced that a heavy landing had occurred and, indeed, were surprised that no damage appeared to have resulted. For this landing, in which the aircraft's attitude was 1° nose-down, the nose and right main gears touched down within approximately one second of each other and within one second in advance of the left main gear, it is probable that the forces imparted to the flight deck from the nosewheel touchdown would have appeared higher than normal to the flight crew.

Co-pilot's landing

During the landing, the co-pilot was unaware of pushing the sidestick fully forward, having intended only to release the backpressure he had been applying. He had no issues with landing the aircraft before the 30 June, and none have been detected since the incident flight. As such, it is considered that the forward sidestick inputs may have been a subconscious reaction to the firm landing event of 30 June, where his commander took over. The co-pilot's landing technique appears to have altered following that landing. The Flight Data Monitoring (FDM) software in use by the operator tracked this change, but the information was not reviewed until after the heavy landing with G-MARA. During a CAA audit of the operator, in February 2008, an observation was raised that the current establishment assigned to FDM oversight appeared inadequate. In response, the operator was in the process of increasing staffing numbers at the time of the accident.

Heavier than desired landings occur throughout the industry, for a range of reasons, and damage occasionally results. The critical requirement is that the aircraft is not then dispatched without this damage being identified and rectified.

Automatic LOAD <15> report

The AIDS is a centralised system which automatically collects and processes aircraft information for the purpose of supporting Aircraft Performance Monitoring (APM), Engine Condition Monitoring (ECM) and APU Condition Monitoring (ACM) programs. For G-MARA, the AIDS consists of a remote print function (located on the flight deck centre pedestal), a Data Management Unit (DMU) and the option to equip the aircraft with a Digital AIDS Recorder (DAR). Over 3,000 parameters are available to the DMU for display, monitoring and recording.

APM, ECM and ACM functions are supported by DMU generated reports, with a report being generated when programmed trigger mechanisms are activated. Upon report activation, the DMU collects groups of parameters specific to the report. Once generated, a report may then be printed on the flight deck, copied to the DAR or sent via the Aircraft Communication Addressing and Reporting System (ACARS) direct to the operator. In addition to the automatic generation of reports, a manual report function is also available through the flight deck Multi Function Control Display Unit (MCDU) or remote print function. When a report has been manually generated, parameters in the report will be collected immediately and independently of any other 'start based' logic. A manual report may then be printed, copied to the DAR or sent via ACARS in the same way as one that was automatically generated.

A structural exceedence report, termed LOAD <15>, was introduced following a hard landing of an A320 aircraft on 3 March 1994. Following that hard landing, the aircraft flew another three flights before problems with landing gear retraction, were discovered. Examination revealed the left gear had suffered a fracture of the upper diaphragm tube and the right gear had an ovalised upper diaphragm tube. Had the landing parameter limits been exceeded, a LOAD <15> report[3] would have been available on G-MARA after the accident.

Within the LOAD <15> report, a landing is determined by activation of either of the main gear oleo compression switches; nose gear oleo compression is not used within the landing detection logic. A LOAD <15> report will automatically be generated during a landing if any of the following conditions are met:

- The normal acceleration is greater than 2.6g at landing (+/-0.5 second). If the aircraft weight exceeds the maximum landing gross weight, the normal acceleration limit is reduced to 1.7g
- The radio altimeter descent rate is greater than 9 ft/sec at landing (+/-0.5 second). If the aircraft weight exceeds the maximum landing gross weight, the radio altimeter descent rate limit is reduced to 6 ft/se.
- For a bounced landing, the normal acceleration exceeds 2.6g

The LOAD <15> report was introduced to identify if a hard landing has occurred, and to ensure appropriate inspections are carried out, by reference to the AMM. However, damage to the nose gear assembly was sustained during the landing of G-MARA without exceeding the LOAD <15> report limits set by the aircraft manufacturer. The LOAD <15> report has certain limitations with respect to monitoring of airframe loads and unusual landing attitudes, as discussed below.

The normal acceleration parameter used within the LOAD <15> report computation is provided by an accelerometer mounted near the aircraft's centre of gravity; the same accelerometer is used by the FDR system. The accelerometer, by design, incorporates a filter that attenuates its output above a predefined frequency. Under certain conditions, such as during rapid changes in acceleration, the accelerometer output may not always reflect the maximum attained g level. In addition, acceleration levels experienced at other sections of the airframe, such as the nose gear, may be different from those measured at the centre of gravity during various phases of flight.

Footnote

[3] It should be noted that the provision of the LOAD<15> report for some A320 aircraft required installation of an upgraded DMU. Service Bulletin (SB) A320-31-1124 refers.

Although certain considerations need to be applied when using just one accelerometer for load monitoring, excessive descent rate at landing may also trigger the report. Activation logic relies upon compression of either main gear oleo before determining if an exceedence has occurred. Nose gear compression does not feature in the activation logic. The report may dynamically change exceedence limits dependant upon aircraft gross weight at landing, but the report does not apply alternate limits if the aircraft lands at an unusual attitude, such as in a flat or nose-down attitude.

Manually generated LOAD <15> report

A LOAD <15> report for the incident landing was manually generated by the maintenance staff and printed, Figure 2. The AMM details:

> *'if a report is requested manually with the remote print button, it is generated immediately (independently of any other start logic).'*

The printed report apparently recorded the maximum touchdown acceleration (VRTA) as 0.95g. However, the DMU was manufactured by Teledyne Controls and loaded with software part number FLY2240A1BXX312. The manufacturer later confirmed that with this software standard a manually generated LOAD <15> report would not contain stored parameters from a previous landing and that the parameter values actually related to the aircraft being parked at Manchester.

Prior to this investigation, the operator reviewed data from another of its A321 aircraft whose landing had been reported as heavy by the flight crew. After this landing, the AIDS had been checked for a LOAD <15> report, but none was found. The aircraft was at an outstation and the operator wanted to understand the severity of the landing before releasing the aircraft back into service. As at most outstations, there was no facility to read out the FDR or QAR. A manually generated LOAD <15> report was printed, Figure 3. The report appeared to provide data from the landing, with both the acceleration and radio altimeter descent rate being below AMM limits. The aircraft was subsequently released back into service. Upon return to the operator's main base, the QAR was read out. Data from the QAR confirmed that the manually generated report had contained the landing information. The aircraft was equipped with a different DMU from that on G-MARA; this DMU was manufactured by Sagem Avionics, part number ED45A300, software part number 360-03795-015, data base V1423. Following the findings from the G-MARA event, the operator inspected the other aircraft for damage but none was found.

Following a review of the AMM hard/overweight inspection procedure, it was identified that the subtask that checked for, and printed, a LOAD <15> report contained a note reflecting that a manually generated LOAD <15> report was not to be used to confirm if a hard/overweight landing had occurred. A manually generated LOAD <15> report may be identified by the Trigger code 1000 appearing on row C1 of the report, Figures 2 and 3.

Aircraft examination

Nose landing gear damage

Discussions with the landing gear manufacturer revealed that they had previously seen similar damage to the inner cylinder of nose landing gear legs, Figure 4. They advised that the collapse of the inner cylinder is the direct result of very high damping pressures which act between the inner and outer cylinders, which typically occur during a very hard three point landing[4],

Footnote

4 A three point landing is one where all three landing gears touch down at the same time.

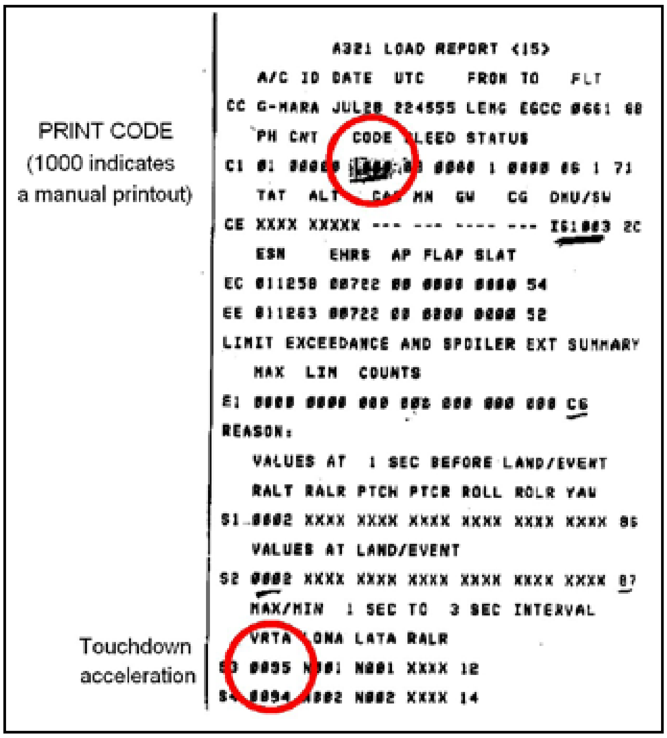

Figure 2

Teledyne Controls DMU
G-MARA post-landing manually generated LOAD <15> report

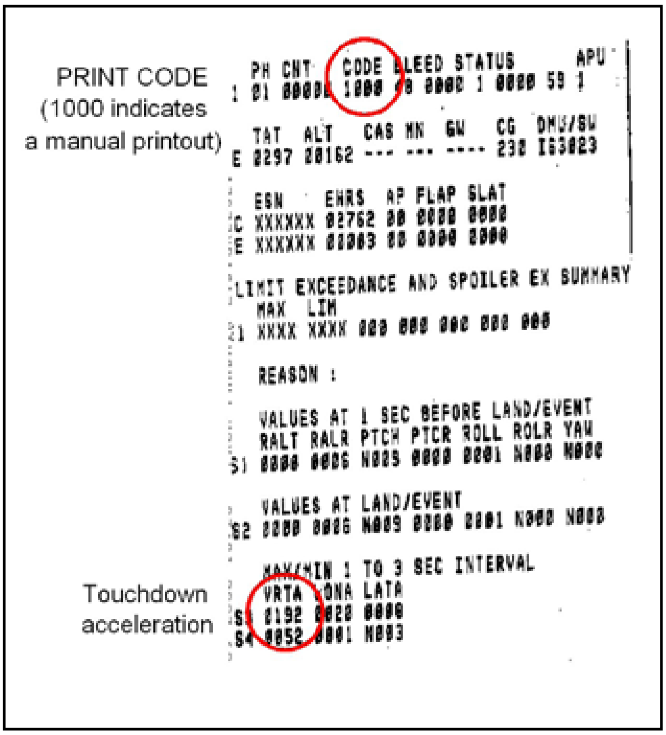

Figure 3

Sagem Avionics DMU
Post-landing manually generated LOAD <15> report

or a nose gear first landing. The damage only occurs when the certificated design criteria for the landing gear is grossly exceeded.

Previous analysis of the link rod which moves the target for the gear-extended proximity sensor through its range of movement showed that, in cases of full leg compression, it is possible for the link rod to be bent by contact with the fixed leg. On this occasion, the rod was bent and witness marks were present on both the rod and the fixed leg which confirmed that contact had occurred, Figure 5.

The landing gear manufacturer identified a number of previous cases where the link rod had been found bent, attributing this to a lack of greasing and ingress of dirt, causing the bearings to seize and impart bending loads in the link as the gear compresses. In response to this issue, two modifications were introduced: the link rod material was changed from aluminium to stainless steel, and different rod end bearings were introduced. These modifications were implemented on the production line and recommended for components already in service. G-MARA had this modification embodied.

Inspection procedure following hard/overweight landing

Task 05-51-11-200-004A of the AMM describes the required inspections after a hard/overweight landing for aircraft with enhanced DMU/FDIMU LOAD <15> report capability. The task defines the categories of hard/overweight landings, and the process for confirmation of the hard/overweight landing, which is in three steps:

Figure 4

View of damaged inner cylinder

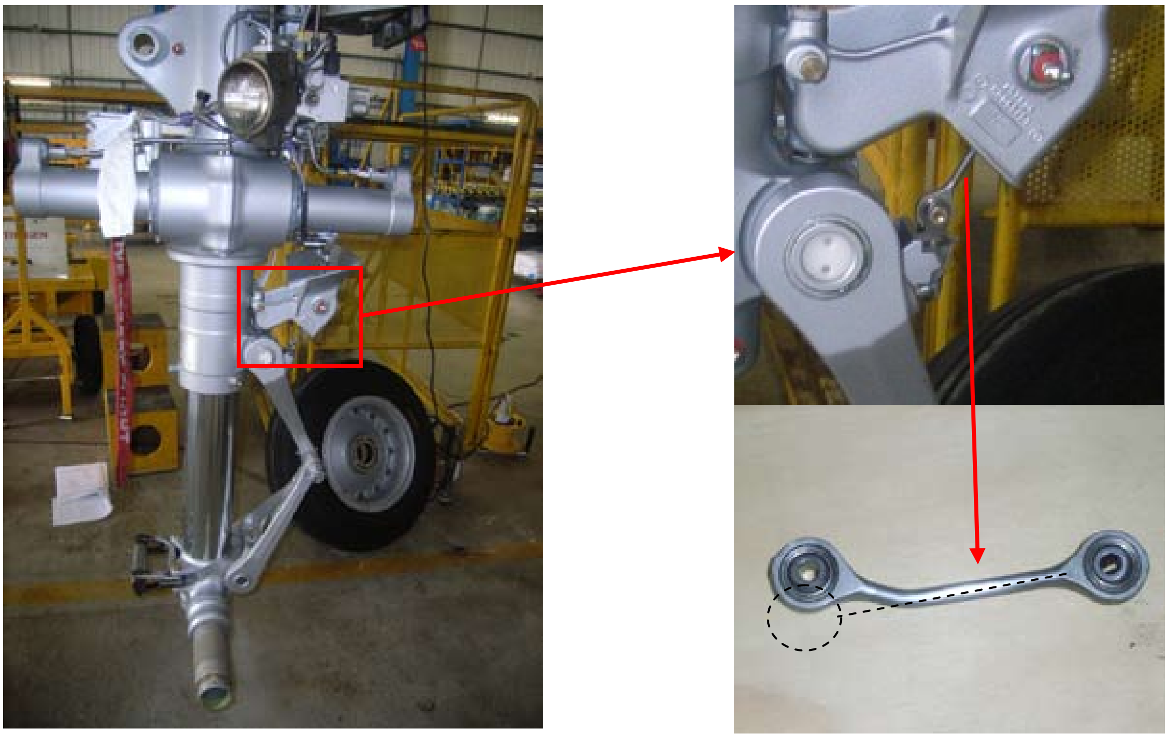

Figure 5

View of replacement nose gear leg showing location of link rod and bent link rod from incident leg

- Flight crew must report if they think a hard/overweight landing was made
- After crew report, impact parameters must be confirmed using either the DMU LOAD <15> report or the FDR readout
- When the category of landing is known, the inspections for that category must be performed

The process then goes on to describe preparation for the inspection, which is in two steps:

> Firstly, it requires that the category of landing is established. If this is not possible then it states that an inspection must be carried out, with the steps appropriate for a severe hard/overweight landing.
>
> Secondly, it requires that information is obtained from the flight crew regarding landing conditions, for example: touch down straight or drifting, wing low; tail or nose heavy; touchdown on main gears or on main and nose gears, or high pitch rate on nose gear; weight of aircraft; quantity of fuel in each tank; instrument indications, and other information such as a noise that could be related to a structural failure. Obtaining the post-flight report is recommended and a reminder is included to do all additional checks related to events specified in the flight crew report or the post-flight report.

The remainder of the task goes on to detail safety precautions and the required inspection tasks. A flow chart that summarises the process to determine the level of inspection is included in the task.

Use of the hard/overweight landing inspection procedure flow chart

On arrival, after the G-MARA flight crew reported the suspected hard landing to the engineer, he followed the AMM process to determine the level of inspection required using the inspection flow chart, Figure 6. The aircraft manufacturer's intended decision making process and that of the engineer's, is illustrated.

After the pilot report of a hard landing, the first decision is:

'DMU load report available.'

The engineer answered YES to this question as the equipment was fitted and serviceable, ie, if the limits had been exceeded, he would have expected to see a report. This answer then gives three options depending on the severity of the touchdown. The first option is:

'DMU shows IRALRI <10 ft/sec and VRTA < 2.6g for a hard landing.'

The engineer chose this option, as a DMU LOAD <15> report had not been generated, indicating that neither of these limits had been exceeded. This choice leads to the conclusion that no more steps are required.

The aircraft manufacturer's view of how this decision process should have been applied is as follows:

After the pilot report of a hard landing, the answer to the first decision:

'DMU load report available.'

was expected to be NO, as a DMU LOAD <15> report was not produced. This answer would lead to the next decision:

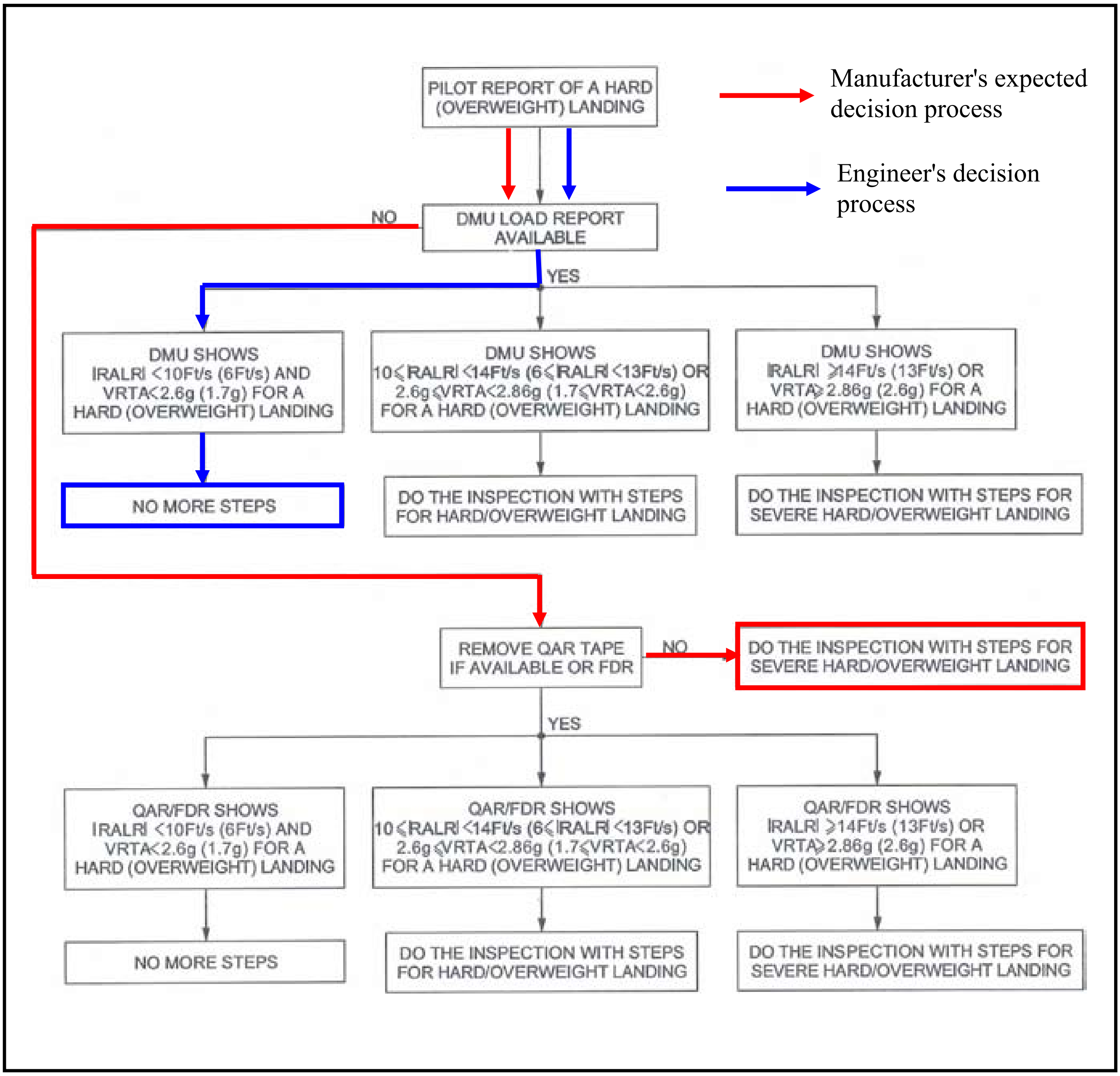

Figure 6

Flow chart for determining category of hard/overweight landing

'Remove QAR tape if available or FDR.'

This was not done, so the answer was NO, which leads to the conclusion:

'Do the inspection with steps for severe hard landing.'

This inspection requires extensive checks and includes jacking the aircraft and functional checks of retraction and extension of the landing gear. Had these checks been completed, it is likely that the damage to the nose landing gear would have been found.

The procedure for determining the level of inspection does not cover all situations and can, as in this case, be interpreted in a different way from that intended by the manufacturer. The DMU LOAD <15> report will only be produced if the recorded parameters exceed pre-determined values. The manufacturer's use of the flow chart implies that a report will be produced even if the parameters are not exceeded. Had the QAR or FDR been replayed as part of the decision making process, the data would also have shown that neither the descent rate nor the normal acceleration limits had been exceeded and, therefore, no inspection would have been required.

Other relevant information

In September 2005 the Aerospace Industries Association (AIA) published a Best Practices Guide for inspection processes following high load events (AIA Publication 05-01). The guide was produced by an industry committee consisting of representatives from the AIA, the Air Transport Association (ATA), aircraft manufacturers, operators and regulators. This was in response to safety recommendations made by the National Transportation Safety Board (NTSB) to address concerns that aircraft may encounter high load events during which structural damage occurs, and where the damage may not be found before returning the aircraft to service.

The committee evaluated existing special inspection procedures against five criteria to ensure they were robust and concluded that, for the most part, they were. However, several areas for improvement were identified, in particular, for future aircraft. These included developing clear inspection procedures, evaluation of high load event measured data and the development of systems to allow the quick and effective use of recorded flight data; this should include annunciation in a manner to provide optimum visibility by all stakeholders.

Manufacturer's actions

Following publication of the Best Practice guide, the manufacturer of the aircraft involved in this event set up an internal working group in 2006 to establish their 'hard landing' experience and identify any associated operational and maintenance enhancements. The group made several recommendations, including the simplification of the AMM procedure and ensuring consistent procedures across their range of aircraft. The group noted that, in line with industry policy, the pilot remains the key decision maker. In September 2008, the manufacturer provided a statement to the European Aviation Safety Agency (EASA) stating that they considered the declaration of a high load event is always under the primary responsibility of the flight crew.

Since the internal review, the manufacturer has been working on updating and aligning procedures in the AMM and the next revision, scheduled for release later in 2009, will include additional guidance for maintenance staff following unusual landings such as nose gear first or bounced landings. In addition, revised trigger points for inspections will be defined within a RED, AMBER, GREEN chart that includes consideration of both vertical and lateral loadings as well as factors to account for landing weight.

Summary

The co-pilot made an unusual pitch input whilst the aircraft was in the flare, causing it to land in a slightly nose-down attitude, resulting in the nosewheel touching down first, and also to bounce. The suspected hard landing was reported by the crew, as required. Following a review of the co-pilot's past performance, the operator conducted additional simulator, base and line training with him and, as no issues were identified during this period, the co-pilot was released back to line flying.

The ground engineer, using the AMM flow chart, determined that an inspection was not required, as the recorded radio altimeter rate of descent and normal acceleration values had not exceeded the limits set by the manufacturer. Thus, as no LOAD<15> report was generated a download of the QAR or FDR was not required. The aircraft manufacturer intended the flow chart to be interpreted in a different way and this would have led to the discovery of the damage. A development of the process for determining the inspections required after an unusual landing, resulting from the manufacturer's working group review of the AIA Best Practice Guide, is due to appear in an AMM revision later in 2009.

The AIA Best Practice Guide notes that the pilot remains the key decision maker when determining unusual landings but recommends making the best use of recorded flight data to evaluate a broad range of events, including annunciation in a manner to provide optimum visibility by all stake holders.

The manufacturer's philosophy is to assign the flight crew primary responsibility for declaring potential high load events, but the importance of communicating the aircraft attitude in unusual landings is not clearly explained in documentation available to the flight crew. The AMM contains detailed descriptions of landing conditions that are considered unusual but this information is not readily available to the flight crew.

The only visual indication that the nose landing gear had been fully compressed was the bent proximity target link rod. An inspection for such damage is not referred to in the AMM and such damage is not readily apparent.

The following Safety Recommendations are therefore made:

Safety Recommendation 2008-092

It is recommended that Airbus includes, in the appropriate publications, further information and guidance to flight crew with regard to unusual landings to ensure they are able to properly discharge their responsibilities to declare potential high load events.

Safety Recommendation 2008-093

It is recommended that Airbus review the landing parameters recorded on any of their aircraft types which are able to produce a LOAD<15> report, so that a LOAD<15> report is generated whenever there is potential for damage to be caused to the aircraft and/or its landing gear following both hard/overweight landings or abnormal landings, such as nosewheel first landings.

Safety Recommendation 2009-047

It is recommended that Airbus include a specific reference in the AMM to inspecting the nose landing gear proximity target link rod for damage as, due to the landing gear geometry, it is a likely indicator of full nose landing gear compression.

An investigation into an incident to another aircraft from the same family has drawn similar conclusions relating to the determination and reporting of unusual landings and the subsequent required inspections. The safety recommendations in this report are complimentary to those made in AAIB report EW/C2008/07/02, the texts of which are included below for completeness.

'It is recommended that Airbus ensure that the generation of a LOAD<15> report by the DMU following a landing parameter exceedance, is indicated to the flight crew involved to enable them to record it in the aircraft's technical log.

It is recommended that the Civil Aviation Authority require operators to provide training in the procedures associated with the reporting of suspected hard landings and the information available to assist decision making on reporting for the aircraft types operated. This should include, for Airbus types, the nature, significance and interpretation of Airbus LOAD<15> reports.

It is recommended that the European Aviation Safety Agency ensure adequate training is provided for ground engineers maintaining Airbus aircraft regarding the correct approach to troubleshooting suspected hard landings and the correct means of obtaining and interpreting the Airbus LOAD<15> report.

It is recommended that Airbus review their procedure for identifying and classifying parameter exceedances based on data recorded by the aircraft during landing, either to ensure that all sources of recorded data give the same outcome or to provide guidance on which source of data should take precedence in the event of a discrepancy. Changes resulting from this review should be reflected in the relevant maintenance manual tasks.'

SERIOUS INCIDENT

Aircraft Type and Registration:	Avro RJ100, G-BZAW
No & Type of Engines:	4 Lycoming LF507-1F turbofan engines
Year of Manufacture:	1999
Date & Time (UTC):	5 February 2009 at 1333 hrs
Location:	London City Airport
Type of Flight:	Commercial Air Transport (Passenger)
Persons on Board:	Crew - 5 Passengers - 24
Injuries:	Crew - None Passengers - None
Nature of Damage:	Extensive damage to the left nosewheel and its axle
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	50 years
Commander's Flying Experience:	12,870 hours (of which 8,870 were on type) Last 90 days - 206 hours Last 28 days - 57 hours
Information Source:	AAIB Field Investigation

Synopsis

After landing, the flight crew felt a judder from the nosewheel during a 180° turn on the runway and the judder returned intermittently during the taxi-in. The aircraft was stopped to allow a visual inspection which identified that the left nosewheel was no longer properly attached. The passengers and crew were disembarked normally. Investigation of the damaged parts identified that the outer bearing of the left nosewheel had failed due to the roller cage becoming trapped. It is not possible to say which of the two potential causes led to the failure. Whilst no recommendations are made, this event is a reminder of the importance of following manufacturer's procedures to inspect and install all aircraft wheel bearings correctly.

History of the flight

The aircraft was operating a scheduled flight from Glasgow Airport to London City Airport, which was uneventful until after the landing on Runway 10. In order to vacate the runway, the aircraft executed a 180° turn to the left in the turning circle. During this turn, the flight crew felt the aircraft judder. They initially attributed this to the nosewheel skidding on the wet runway markings. As the aircraft back-tracked along the runway, the flight crew felt an intermittent judder which they now thought might be due to a deflating tyre. Shortly after turning onto Taxiway C the aircraft was stopped partly clear of the runway to allow the nose landing gear to be inspected. This revealed that the left nosewheel was no longer properly attached. The cabin crew and passengers were informed and they disembarked from the aircraft normally. There were no injuries.

Recorded flight data

The aircraft was equipped with a flight data recorder (FDR) and a cockpit voice recorder (CVR), capable of recording a minimum duration of 25 hours of data and 120 minutes of audio respectively. Both were successfully replayed. The FDR record contained all 16 flights since the left nosewheel had been installed. The CVR record included the approach and landing at London City Airport.

The FDR record was analysed for unusual or abnormal aircraft operation that may have resulted in, or contributed to, failure of the nosewheel assembly. The incident landing at London City was analysed. Peak Normal acceleration at landing was 1.49g with the main landing gear contacting the runway surface about one second prior to the nose gear. Rate of descent at touchdown was less than 5 ft/sec, below the aircraft manufacturer's 'hard landing' descent rate limit of 10 ft/sec. Of the 15 preceding flights, one showed a similar level of Normal acceleration at landing, although well below that which would require a hard landing inspection. In addition to hard or unusual landing attitudes, rapid de-rotation during landing may result in higher than normal loads being placed on the nose gear and wheel assemblies. From the incident flight, the de-rotation rate was calculated to be about 3°/sec. This was higher, by about 1.5°/sec, than all but one of the preceding flights; the flight having a higher de-rotation occurred 11 flights prior to the incident flight.

The FDR record was also analysed by the operator's Flight Data Monitoring (FDM) system. If an anomaly in the operation of the aircraft were identified, the system would automatically produce a report. No reports were generated for either the incident or preceding flights.

Engineering examination

Both nosewheels were removed from the aircraft. The left wheel and its bearings were found to be severely damaged and parts of the bearings were recovered from the runway and Taxiway C. Subsequent inspection found damage to the nosewheel axle assembly and it was replaced. Both nosewheels and all the damaged parts were taken initially to the AAIB facilities.

A detailed examination of the damaged parts was conducted under AAIB supervision at the wheel manufacturer's overhaul premises by their technical support engineers and a technical representative of the bearing manufacturer. This examination identified that the outer bearing of the left nosewheel had failed first; the inner bearing, wheel and axle damage were as a result of this initial failure. A detailed examination of the outer bearing found that the damage had occurred rapidly, as most of the rollers still had their original surface finish intact and their ends were not deformed. Witness marks on the raceways indicated that the rollers had not skewed and the tips of the rollers were not burnt, indicating that there had been sufficient lubrication. This evidence led to the conclusion that the roller cage had become trapped and then severely damaged, which allowed the rollers to move and 'clump together' within the bearing. The bearing manufacturer stated that there are two possible reasons for the cage becoming trapped: wear in the cage pockets or, in their opinion more probably, insufficient pre-load on the bearings.

Nosewheel maintenance history

The wheel in this incident was manufactured in February 1998 and had completed 4,470 cycles since its previous overhaul. It had been returned to the manufacturer for a tyre replacement in December 2008. In order to replace the tyre, the two halves of the wheel have to be separated. The wheel bearings are removed, cleaned and inspected and, if their condition is satisfactory for further service, they are greased and re-installed in the wheel. Because of this 'on condition' assessment of bearing serviceability, it is not possible to determine how long the bearing had been in service as there is no requirement to record its service life.

The fitters conducting the work receive regular continuation training to ensure their knowledge for the task is at a suitable level. The person inspecting the bearings completed continuation training, provided by the bearing manufacturer, in April 2008.

The wheel assembly was released from the manufacturer on 20 January 2009, in a certified 'fit for service' condition.

Aircraft maintenance history

The wheel assembly was fitted to the aircraft on 30 January 2009 in the left-hand position and the aircraft had operated for 16 cycles prior to the failure. It was installed by two licenced aircraft maintenance engineers (LAMEs) during a routine overnight inspection. The wheel was replaced in accordance with the Aircraft Maintenance Manual (AMM). Both LAMEs, who were familiar with the task and had changed nosewheels on this type of aircraft numerous times, reported that no problems were encountered during the task. Although it was night, adequate lighting was provided from their vehicle lights and portable halogen lights provided by the operator. The weather was cold and drizzly but neither LAME felt this affected the task. The only real distraction mentioned was a noisy diesel ground power unit supplying electrical power to the aircraft.

In order to correctly seat the wheel, the AMM requires that the axle wheel nut is first torqued to a relatively high figure to seat the wheel bearings, before the nut is undone and then re-torqued to the in-service value. Whilst the torque is being applied on each occasion, the wheel must be rotated to ensure the bearings take up their correct positions.

Both of the LAMEs involved were certain that this procedure was followed with one rotating the wheel whilst the other tightened the axle wheel nut to the specified torque value with a torque wrench.

The torque wrench used for the wheel installation was removed from service and was sent for calibration. The results of this testing showed that the torque wrench calibration was within satisfactory limits throughout its range.

The operator issued an Engineering Technical Requirement on 18 February 2009, to conduct a fleet-wide check of each nosewheel installation for correct axle nut torque. All the aircraft in the operator's fleet were checked, with no adverse findings.

In-service history

The aircraft manufacturer has only two recorded reports relating to failed nosewheel bearings since the start of their present database in 2000.

The most recent, in March 2008, was attributed to a lack of grease in the bearing which resulted in excessive heat, no corrosion protection, accelerated wear and ultimately failure of the bearing. It is thought by the aircraft manufacturer that the lack of grease was caused by the operator's washing procedures, rather than insufficient grease being applied during maintenance. The AMM is being updated to prohibit, more definitely, cleaning without wheel covers.

The other report, in November 2003, more closely resembles the event to G-BZAW on 5 February 2009, and was attributed to a trapped bearing cage. The likely cause was identified, in order of probability, as excessive bearing adjustment clearance due to inadequate or incorrectly applied axle nut torque, inadequate lubrication, or a bearing with an excessively worn cage refitted to the wheel.

Discussion

Although the incident landing could be considered as being 'firm', it was well below the aircraft manufacturer's hard landing inspection limits. The landing attitude was also normal. Of the preceding 15 flights, none were found to have an unusual landing attitude or to approach the aircraft manufacturer's hard landing inspection limits. Analysis indicated that the de-rotation rate was above average but was not excessive. It is thus unlikely that failure of the nosewheel bearing was a direct result of damage sustained during flight operations.

Analysis of the failed bearing indicated that the cause of failure was the roller cage becoming trapped. This was a rapid event and would have occurred during the incident landing. There are two potential reasons for the cage becoming trapped on this occasion: excessive wear in the roller pockets of the bearing cage, or insufficient bearing pre-load, caused by insufficient tightening of the axle wheel nut or failure to rotate the wheel sufficiently whilst the torque was applied.

During the last workshop visit, the wheel and bearings were inspected by the wheel manufacturer's staff and a suitably trained person undertook and certified the inspection activity. The wheel was fitted to the aircraft by two appropriately qualified LAMEs, following the Aircraft Maintenance Manual procedure and using a calibrated torque wrench. Both had completed nosewheel replacements on this type of aircraft on many previous occasions.

Conclusion

The failure mechanism of the bearing has been identified but it is not possible to say which of the two potential causes led to the failure. Whilst no safety recommendations are made, this event is a reminder of the importance of following manufacturers' procedures to inspect and install all aircraft wheel bearings correctly.

SERIOUS INCIDENT

Aircraft Type and Registration:	Boeing 747-412, B-KAG
No & Type of Engines:	4 Pratt & Whitney PW4056 turbofan engines
Year of Manufacture:	1992
Date & Time (UTC):	1 March 2008 at 0128 hrs
Location:	Manchester Airport
Type of Flight:	Commercial Air Transport (Cargo)
Persons on Board:	Crew - 2 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	Damage to Nos. 1, 2 and 4 engine nacelles, one main landing gear tyre ruptured
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	48 years
Commander's Flying Experience:	10,800 hours (of which 699 were on type) Last 90 days - 188 hours Last 28 days - 55 hours
Information Source:	AAIB Field Investigation

Synopsis

The aircraft was landing at Manchester Airport on Runway 23R at the end of a scheduled cargo flight from Dubai. There was a strong wind from the north-west and a number of aircraft had earlier diverted to other aerodromes.

During final approach, the crew received a windshear warning when the aircraft was at 500 ft agl. They carried out a missed approach and were given radar vectors for another ILS approach. The second approach was described as smoother but still with a strong wind from the north-west, resulting in a crosswind from the right which was close to the operator's limit for landing this aircraft. During the ensuing touchdown the aircraft rolled right and the No 4 engine nacelle made contact with the runway surface. The aircraft then rolled left and Nos 1 and 2 engine nacelles also made contact with the runway and the No 2 tyre on the left main landing gear burst. There were no abnormal indications on the engine instruments and, after an external safety check by the Airport Firefighting and Rescue Service, the aircraft taxied on to a stand.

History of the flight

During the pre-flight briefing for their scheduled cargo service from Dubai to Manchester, the flight crew noted that there were strong winds forecast throughout northern Europe. In particular, the forecast for

Manchester Airport predicted crosswinds which would be outside the co-pilot's 20 kt limit at their estimated time of arrival. Consequently, it was agreed that the commander would act as the pilot flying (PF). Also, in view of the weather forecast, the crew uplifted an extra 2 tonnes of fuel in anticipation of a potential diversion, should that be necessary - 'two approaches before diverting' being the company standard procedure.

The flight was uneventful, apart from a minor problem with the transponder, and, en route, the crew monitored the weather at their destination and potential alternates. Because of the possibility that they might not be able to land at Manchester, the crew contacted their company during the flight to confirm the preferred priority of alternate destinations. They were advised that Nottingham East Midlands was the number one alternate, with London Heathrow as the second.

As they neared Manchester, the crew noted that the Airport's Aeronautical Terminal Information Service (ATIS) arrival information included a warning that moderate to severe turbulence had been reported on the approach to Runway 23R at a range of 16 nm to 10 nm. They did not experience this and established the aircraft on a Category 1 ILS approach to Runway 23R with 30° of flap selected. During the course of the approach the aircraft's airspeed increased above the flap limiting speed and the aircraft's flap load relief system automatically reduced the flap setting to 25°, until the airspeed had reduced sufficiently for flap 30° to be redeployed automatically.

Immediately following the aural annunciation "FIVE HUNDRED" on the flight deck, which is triggered when the aircraft descends through a radio altimeter height of 500 feet, the crew received the aural and instrument indications associated with a windshear warning. Without delay they carried out a missed approach. (The commander later commented that this was the first windshear warning that she had experienced as a result of actual conditions.) The crew advised ATC and requested radar vectors for a second ILS approach to the same runway, for which the Decision Altitude was 450 ft amsl (airport elevation 257 ft). They rebriefed and decided to carry out the second approach with 25° of flap selected, a permitted setting, because of the speed fluctuations and windshear during the first approach.

The second approach was described as being smoother. Approaching a range of 11 nm from the runway, ATC advised the crew that the aircraft ahead had landed successfully. It was established subsequently that this was an Airbus A321 belonging to another operator. B-KAG was fully configured for landing and stabilised on the ILS glideslope and localiser by 1,500 ft aal, and the landing checklist was completed by 1,000 ft aal.

During B-KAG's final approach ATC transmitted a number of surface wind readings. When the aircraft was cleared to land, the crew were advised that the surface wind was 280°/20 KT MAXIMUM 36 KT. Following that, ATC transmitted three instantaneous surface wind readings; 280°/37 kt, 300°/31 kt and 290°/31kt. The aircraft again produced a "FIVE HUNDRED" aural annunciation, followed by another saying "ONE HUNDRED" as the commander disengaged the autopilot and disconnected the autothrust. The co-pilot advised the commander that the aircraft was at the correct approach speed with a 700 fpm rate of descent and ATC transmitted the final instantaneous wind. The aural alert "MINIMUMS" was emitted on the flight deck, confirmed by the co-pilot, and the commander called "LAND". In quick succession, the co-pilot advised her that the rate of descent was 900 fpm, an aural "SINK RATE" warning was generated twice, backed up by the same call from the co-pilot, a "TEN" [feet] aural alert sounded and the aircraft landed. Later, the commander recalled seeing a rate of descent of 1,100 fpm on the flight instruments at the time of the 'sink rate' warning.

During the rollout, ATC advised the crew that sparks had been seen coming from both wings and that the wings, or some of the engines, had touched the runway during the landing. This was confirmed by a member of the airfield operations staff, who was in a vehicle positioned adjacent to the touchdown zone on Runway 23R. The rollout was completed without further incident and the commander checked that the engine instruments were indicating normally before taxiing the aircraft clear of the runway. She then stopped B-KAG on a taxiway and the Airport Firefighting and Rescue Service (AFRS) attended the aircraft to carry out an external inspection. They reported damage to the Nos 1 and 4 engine cowlings but no signs of any fuel or hydraulic fluid leak. With the agreement of the AFRS, the commander taxied the aircraft slowly on to a stand and the crew shut B-KAG down.

Meteorology

At the time of the occurrence, an area of low pressure lay to the north-east of the United Kingdom resulting in strong to gale force north-westerly winds across north-west England.

The Terminal Area Forecast (TAF) for Manchester Airport for the period from 2200 hrs on 29 February to 0700 hrs on 1 March 2008 forecast a surface wind from 260° at 22 kt, gusting to 35 kt, with visibility in excess of 10 kilometres and scattered cloud at 2,000 ft agl. Temporarily during the period from 2200 hrs to 0300 hrs the surface wind was forecast to veer to 270° and increase to 28 kt, with gusts to 45 kt. There was also a 30% probability of a temporary change between 2200 hrs and 0700 hrs when the visibility would reduce to 7,000 metres in showers of rain and there would be broken cloud at 1,200 ft agl.

The ATIS arrival information for Manchester Airport at 0050 hrs reported the surface wind as 280°/25 gusting 42 kt, visibility greater than 10 kilometres, few cloud at 2,800 ft agl, scattered cloud at 3,200 ft agl and a wet runway. This arrival information also included a report of moderate to severe turbulence on the approach to Runway 23R between 16 nm and 10 nm. The next ATIS arrival information, timed at 0120 hrs, when B-KAG was making its second approach to land, reported the surface wind as being 300°/28 gusting 42 kt. The visibility was still greater than 10 km, there were few clouds at 3,200 ft agl and the runway continued to be wet. The QNH pressure setting was 994 mb.

The UK Air Pilot entry for Manchester Airport contains the following warning:

> *'Pilots are warned, when landing on Runway 23R in strong north westerly winds, of the possibility of turbulence and large windshear effects.'*

Between 0020 hrs and 0220 hrs, the surface wind at Nottingham East Midlands Airport was blowing down the runway at comparable speeds. At London Heathrow Airport a similar situation existed. At both, the visibility and cloudbase were suitable for an approach and landing.

Other aircraft

Between 2115 hrs and 0120 hrs on the same night, ATC logged 10 aircraft, including B-KAG, which carried out go-arounds due to windshear, turbulence or the strength of the crosswind. Of these, five diverted to other aerodromes.

Aircraft loading

The landing weight of the aircraft was 257.8 tonnes, which was less than the maximum landing weight of 295.7 tonnes. The centre of gravity (CG) was at 21.1% Mean Aerodynamic Chord (MAC), towards the centre of the permitted range.

Personnel

Earlier in the day, the commander had flown the aircraft from Hong Kong to Dubai: a Flight Duty Period (FDP) of 9 hours 35 minutes. She then had 11 hours rest, the minimum permitted, during which she slept for 7 to 7½ hours, before reporting for duty and meeting up with the co-pilot. The co-pilot had operated another aircraft from Manchester to Dubai, via Amsterdam. He then had 11 hours 30 minutes rest, achieving about 5 hours sleep. Prior to reporting for duty in Hong Kong for her first sector to Dubai, the commander had had six days off duty.

Neither flight crew reported being fatigued during the two approaches to Manchester, nor was there evidence that it was a factor in the occurrence.

Aircraft description

B-KAG was a B747-400 (s/n 27067) BCF (Boeing Converted Freighter), a freighter conversion of a passenger aircraft. It is a low-winged transport with four engines pylon-mounted below and forward of the wing leading edges (Figure 1). The wingspan is 64.9 m (213 feet) and the overall length is 68.6 m (225 feet). The engines are numbered from left to right, as Nos 1 to 4. The fan duct portion of each engine consists of, from front to rear, a nose cowl, a fan cowl and a translating cowl. The cowl outer skins are predominately of Carbon Reinforced Plastic (CRP).

On the ground, the aircraft is supported on two wing and two body main landing gears (MLG), each with a four-wheeled truck, and a two-wheeled nose landing gear. The MLG wheels are numbered from left to right across the aircraft, front wheels first.

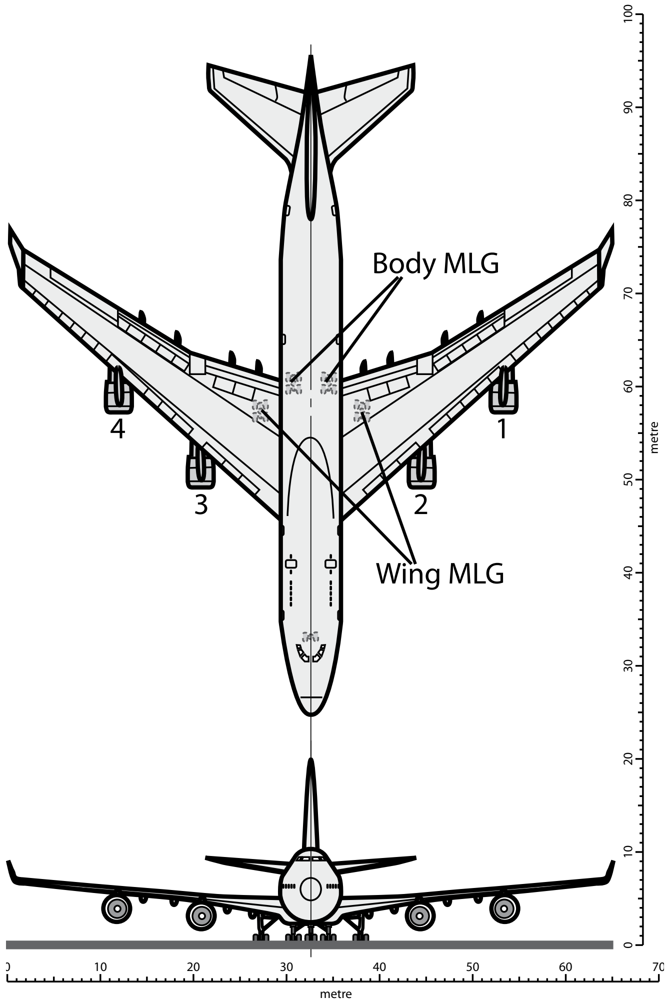

Figure 1

Boeing 747-412 - General arrangement

Nacelle clearance

With the landing gear wheels in ground contact, the clearance of the engine nacelles from the ground is primarily dependent on the combination of aircraft pitch and bank angles. The nominal combinations at which the nacelles contact the ground are shown in Figure 2 (MLG shock struts compressed). Nacelle ground clearance is also affected by wing bending due to aerodynamic and inertial loading. With B-KAG standing on all five landing gears, the average nacelle ground clearance was measured at 1.81 m (5.93 feet) for the outboard nacelles and 0.99 m (3.25 feet) for the inboards.

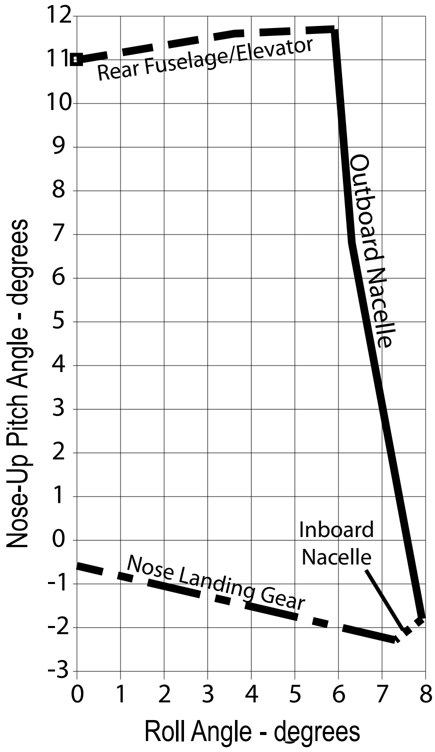

Figure 2

B747-412 Ground contact angles

EGPWS installation

The aircraft was equipped with an Enhanced Ground Proximity Warning System (EGPWS). This system provides audible warnings against terrain-related hazards, windshear events and glideslope deviations. It also provides altitude callouts to aid situational awareness. The system was pin programmed to provide automatic altitude callouts one hundred feet above minimums, at minimums and at radio heights of 2,500 ft, 1,000 ft, 500 ft, 50 ft, 40 ft, 30 ft, 20 ft and 10 ft. These aid situational awareness. These calls are not issued if a higher priority warning, such as the recorded sink rate warning, has been generated.

Runway 23R at Manchester

Runway 23R at Manchester Airport is 3,048 m long and 46 m wide, with an additional 22 m wide paved shoulder on either side. The runway surface is partially concrete and partially asphalt. The published landing distance available (LDA) is 2,865 m. The runway lies south-east of the airport terminal buildings and hangars (Figure 3).

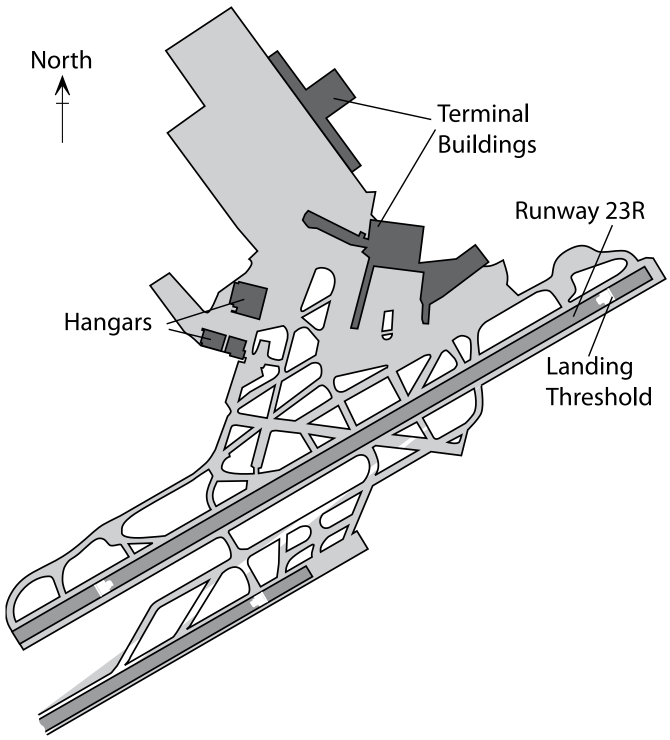

Figure 3

MIA Runway layout

Runway examination

Examination of Runway 23R revealed a number of scrape marks, indicative of nacelle contact, and several tyre track marks that, by virtue of their relative locations and by comparison with the aircraft damage, could be matched to B-KAG's landing (Figure 4).

Other tyre marks from B-KAG may have been present but hidden by the dark-coloured asphalt forming the

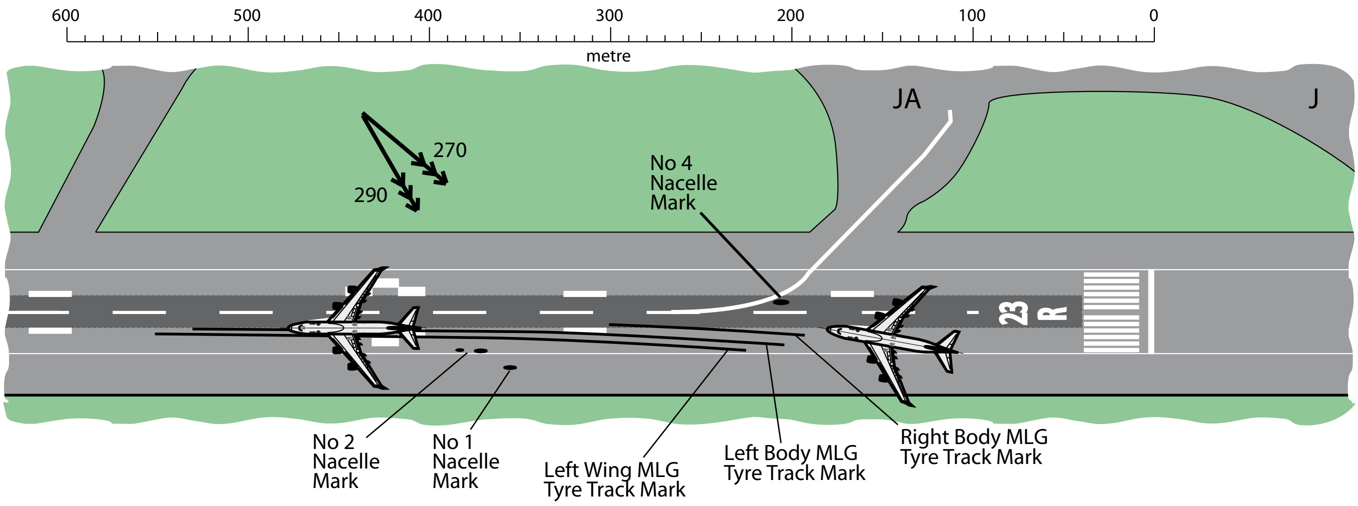

Figure 4

Runway marks

central portion of the runway surface and by multiple heavy tyre smudges present in the touchdown area. The following distances, along the runway from the threshold and left or right of the centreline, are approximate.

The initial mark, from the right body MLG tyres, started around 193 m from the threshold. This was almost immediately followed by a short scrape mark, 6.1 m right of the runway centreline, caused by momentary contact of the No 4 nacelle, and by the start of tracks from the left body MLG tyres. The markings indicated that the aircraft Centre of Gravity (CG) was around 15 m left of the runway centreline at initial touchdown, with the aircraft tracking approximately 4° right of the runway heading. Tracks from the left wing MLG started at 226 m.

The MLG tyre tracks continued, curving to the left. A short scrape mark from the No 1 nacelle started at 359 m and two short scrape marks from the No 2 nacelle started at 375 m. The tyre tracks showed that by around 500 m B-KAG was tracking parallel to the runway, approximately 8 m left of the centreline.

Aircraft Examination

Examination of the aircraft showed that the underside of No 1, 2 and 4 nacelles had sustained scraping and abrasion damage, consistent with having contacted the runway. The most severe damage was to the No 4 nacelle, where the bottom of the nose cowl, fan cowl and translating cowl had been heavily abraded and locally deformed. Distortion of the translating cowl also resulted in minor damage to the HP gearbox driveshaft cover installed on the engine. In the case of the No 1 nacelle, the bottom of the rear part of the nose cowl and the forward part of the fan cowl had been scuffed. The No 2 nacelle suffered locally heavy abrasion damage in the same areas as the No 1.

The direction of the scrape marks indicated that the aircraft had been heading approximately 7° right of its track when the No 4 nacelle contacted the runway.

No evidence of anomalies with the landing gears was found, with the exception of rupture of the No 2 tyre (forward right tyre of the left wing MLG). Tyre pressures measured some hours after the incident were measured at 190-195 psig for all MLG tyres (normally 200-205 psig), except for the ruptured No 2 tyre. MLG shock strut pressure readings were within limits.

The No 2 tyre rupture resulted from a 'flat' worn completely through the carcass, indicative of the wheel having been locked during part of the ground run. No faults with the wheelbraking system were apparent and none was recorded on the aircraft's central maintenance computer (CMC) when the brake control system was tested using its built-in test equipment (BITE). However, an operational check by the operator found that the No 2 brake failed to release to prevent the wheel from locking. Testing revealed that the No 2 anti-skid control valve (PN 39-617, SN 059627620) was inoperative, and that the valve's electrical insulation resistance was below the minimum specified. The type of valve is not 'lifed' and the operator was unable to establish its time in service. While the brake system BITE includes an integrity check of the servo coil in the anti-skid control valve, it would apparently not detect all faults that might render the valve inoperative.

A Boeing Fleet Team Digest (FTD) (No 747-440-FTD-32-04009, issued 24 September 2004) described reports from operators of water ingress into Anti-Skid Control Valves, resulting in corrosion of several parts of the assembly. The FTD noted that in two cases a tyre skid-through had resulted. In all cases the problem had concerned wing MLG valves. These are installed facing down and appeared to be more susceptible to water ingress than the body MLG and alternate anti-skid valves. The valve manufacturer, Crane Hydro-Aire, had issued a Service Information Letter (SIL) (No 39-617-3-12, Revision 1 of 1 July 1994) recommending adding RTV106 sealant at all external interfaces of the servo valve body and cover. A further SIL (No 39-617-2-14, Revision 1 of 16 December 1994) provided for improvements in the valve cover. The FTD noted that even with this configuration it was possible that a water ingress path was present in the connector area.

Flight recorders

Recordings were recovered from the flight data recorder (FDR), a 2-hour cockpit voice recorder (CVR) and the enhanced ground proximity warning system (EGPWS). The following is derived from these recordings and reported in UTC.

The CVR recordings indicated that throughout the flight the crew were communicating fully with each other, discussing the situation and observing procedures, briefings and check lists in a professional manner.

The aircraft took off from Dubai at 1728 hrs on 29 February 2008. The aircraft climbed to cruise at FL340 and then FL360, with a short period at FL380. The descent started at 0049 hrs. During the descent the crew discussed the high wind conditions enroute, at the destination and at alternate airports with reference to the aircraft limits. Whilst enroute, it was stated that the destination airport was at the time "RIGHT ON THE LIMITS" and the others were within limits. Windshear and go-around briefings were made. Emphasis was given to checking the ATIS and ensuring updated surface wind conditions were received.

Passing through 9,000 ft, the surface wind of 290°/30 kt gusting between 31 and 41 kt was reported. This was highlighted by the crew as out of the operator's limits. The decision was made to continue the descent and prepare to go around if the surface wind remained out of limits.

The final descent on the first approach to Runway 23R commenced from 3,500 ft amsl with the three-channel autopilot tracking the glideslope and localizer and with the autothrottle SPEED MODE engaged. The aircraft was flown with 20° of drift to maintain track, reducing with altitude. The flaps were progressively deployed, with FLAP 30 selected at 1,460 ft amsl and 3.3 nm to the threshold. Just prior to the automatic "ONE THOUSAND" altitude callout, the surface wind was reported as 290°/24 kt gusting 42 kt which was described as being "JUST IN". At 490 ft agl and 1.3 nm to go, a windshear warning was triggered by the EGPWS. The autopilot and autothrottle switched to go-around modes, flaps were reduced, gear raised and the crew flew a go-around. Prior to the windshear warning, the drift had reduced to 13°; this changed to 9° in the following 3 seconds.

The aircraft climbed to 3,500 ft amsl, and then 4,000 ft amsl, and was vectored for a second approach. During the go-around the crew elected to make a further attempt to land at Manchester, this time with FLAP 25. As the aircraft captured the localizer the wind was reported as 280°/23 kt gusting between 14 and 36 kt and the crew were informed that the aircraft ahead had landed.

By 10.5 DME, and descending through 3,700 ft amsl, the three autopilot channels were fully coupled to the glideslope and localizer and the autothrust was in speed mode. By 6 DME and 2,200 ft amsl the aircraft was fully configured with gear down and FLAP 25. At this point the aircraft was flying with 16° of drift and reducing. Subsequent wind checks received were 290°/24 kt gusting 36 kt, 290°/23 kt gusting 36 kt and 280°/20 kt gusting 36 kt. At this point the aircraft was cleared to land and the 1,000 ft automatic callout was triggered.

The next call was 280°/21 kt gusting 36 kt. This was followed 13 seconds later by the automatic 500 ft callout and then periodic 'instantaneous' surface winds as shown in Figure 5.

Figures 5 and 6 show the recorded information during the final approach and landing. Of note are the gusty conditions evident in the data. The only wind parameter recorded was the wind direction and this was only recorded once every 4 seconds, which is inadequate for analysis of the prevailing wind conditions.

The autopilot and autothrottle systems were disconnected at approximately 270 ft agl and 220 ft agl, respectively. During this period "MINIMUMS" was called and the captain responded with "LAND". At this point the aircraft was slightly to the right of the centreline and rolling left to recover the centreline. Right pedal and roll inputs were made, checking the left bank and motion at the same time that the wind speed started to ramp up and change direction so it was mostly from the right of the aircraft. The aircraft started yawing right and rolling right. Left control wheel and rudder inputs were made, slowing the rate of roll to the right but not stopping it before touchdown.

At touchdown, the aircraft was to the left of the centreline and had a recorded right roll of 9.7°. This exceeded the nominal 'pod scrape' roll limit for the recorded pitch angle. At the point of touchdown only a small Normal acceleration was measured. However, it is worthy of note that the sensor position is inappropriate for measuring forces at the wing.

The aircraft rolled left and the maximum recorded left roll was 6.7°. This did not exceed the nominal 7.5° pod scrape roll limit for the recorded pitch angle but the peak value of roll may not have been recorded and the pod scrape limit would not account for dynamic flexing of the wing. The rollout then stabilised.

From the recorded data, it is clear that the aircraft was being subjected to a strong crosswind component, with

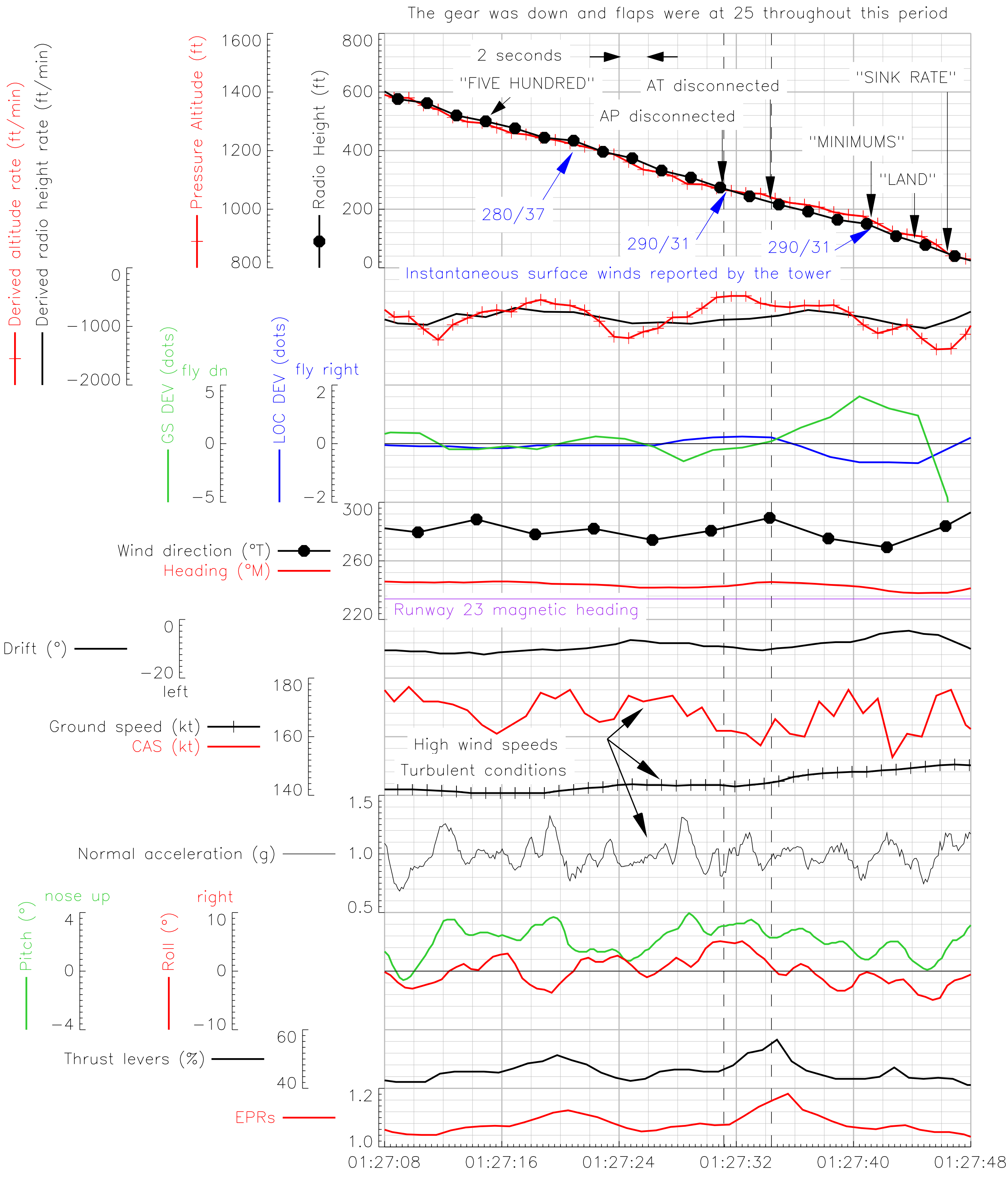

Figure 5

Salient FDR parameters - final approach

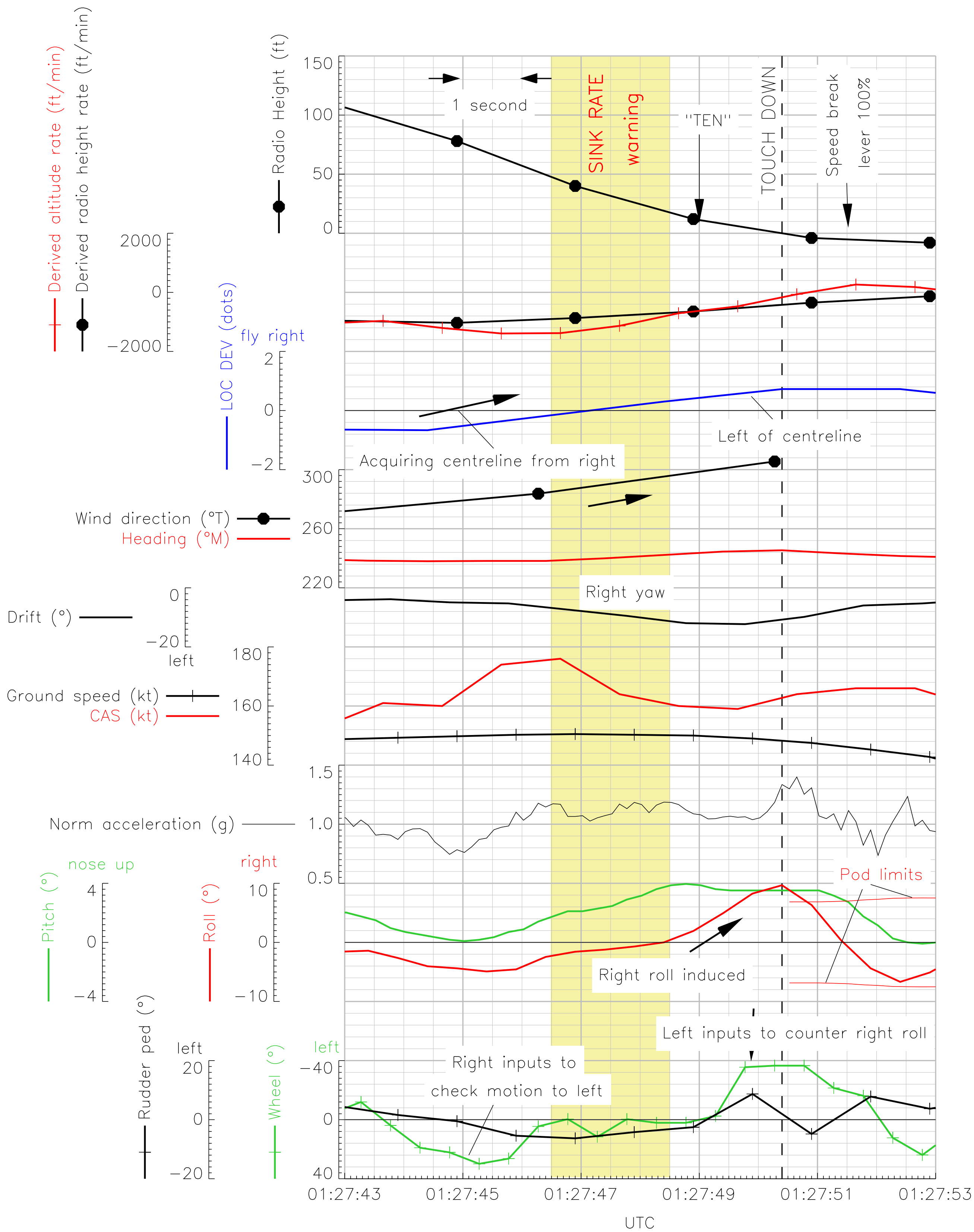

Figure 6

Salient FDR parameters - landing
Flight data analysis by aircraft manufacturer

gusts, and a change in wind direction and speed occurred just prior to touchdown.

An EGPWS sink rate warning was triggered just prior to touchdown and the sink rate was reduced prior to ground contact and only a relatively small normal acceleration was measured at touchdown. The sink rate warning issued by the EGPWS inhibited the majority of altitude callouts in the final stages of the landing.

The aircraft roll at touchdown was sufficiently large to indicate a pod strike on the right engine. The data pertaining to the subsequent left roll did not indicate a pod strike on this side but the limits do not account for flexing and the sample rate of the roll parameter is likely to have missed the peak left roll.

The aircraft manufacturer was provided with flight data and asked for analysis, principally concerning whether the aircraft responded correctly to the crew's control inputs although the sample rate of the wind direction parameter, once every four seconds, was insufficient to assess dynamic wind conditions. The manufacturer used simulation tools that calculated the wind conditions based on the recorded parameters, which improved the understanding of the wind conditions. The calculated wind showed large shifts in direction and magnitude just prior to touchdown.

The simulations and modelling indicated that the aircraft was responding correctly to crew control inputs and that the inputs were appropriate, although their magnitude may have contributed to the likelihood of a nacelle contact.

Operator's procedures

Limitations

The operator's crosswind limit for the Boeing 747-400 when landing on a wet, non-contaminated runway (no standing water, slush, loose or compacted snow, or ice) is 30 kt. The manufacturer's Landing Crosswind Guideline, for the same conditions, is 32 kt. The manufacturer does not regard this as a limitation but, rather, as assistance to operators when establishing their own crosswind policies.

The operator's operations manual repeats the manufacturer's advice:

> *'The crosswind guidelines…. are based on steady (no gust) conditions…. Gust effects were evaluated and tend to increase pilot workload without significantly affecting the recommended guidelines…. '*

Stable approach criteria

Within its '*Approach and Landing Procedure'*, the operations manual provides guidance on a '*Stabilised Approach'*. It states:

> *'In order to comply with company approach requirements, the following should be achieved at or before the altitudes stated:*
>
> - *Landing Configuration by 1,500 ft AAL.*
> - *stabilised on Glideslope/ Final Approach Path by 1,500 ft. AAL.*
>
> *A missed approach is mandatory if any of the following have not been achieved by 1,000 ft. RA:*
>
> - *Landing configuration.*
> - *Stabilised on Glideslope/Final Approach Path.*
> - *Stabilised at Command Speed taking into consideration the prevailing conditions.*
> - *Landing Checklist complete.'*

Next, under the heading *'Mandatory Missed Approach'*, it states:

> *'A Missed Approach is mandatory and shall be executed by the PF immediately if:*
>
> - *The aircraft has not achieved the parameters defined under the stabilised approach, or…*
> - *The successful outcome of the manoeuvre is in doubt, or….*
> - *The Captain announces "Go-Around".'*

Approach speed

The operations manual's guidance on approach speed stated:

> *'If the auto-throttles are disconnected, or are planned to be disconnected prior to landing, position the MCP Command Speed to VREF [the landing reference speed] plus:*
>
> - *½ the steady wind component, and*
> - *All the gust.*
>
> *The maximum wind/gust additive to VREF is 20 kt....*
>
> *The gust correction should be maintained to touchdown while the steady headwind correction may be bled off as the aircraft approaches touchdown.'*

On this basis, the appropriate approach speed, in view of the surface winds broadcast on the ATIS and reported by ATC when the aircraft was cleared to land, was V_{REF} + 20 kt; the gust factor being at least 14 kt.

The landing weight of the aircraft was 257.8 tonnes, for which the FLAP 25 V_{REF} was 152 kt, and the crew set a Command Speed of 167 kt (V_{REF} plus 15 kt). The appropriate Command Speed, for the conditions, was 172 kt and the target speed at touchdown was 166 kt.

Approach monitoring

The operations manual provides guidance for the Pilot Not Flying (PNF) during an approach to land. It states:

> *'The PM [pilot monitoring] shall monitor approach parameters and call any abnormal indications or deviations….*
>
> ***Above DH, MDA or above 500 ft. AAL on Visual Approach (below 2500 ft. RA).***
>
> *Airspeed and descent rate calls may be omitted if the PF [pilot flying] is controlling the IAS and rate of descent satisfactorily.*
>
> *Satisfactorily is defined as Command Airspeed plus 10 kt. to minus 5 kt. and rate of descent less than 1000 fpm below 1000 ft. AAL.*
>
> *If these tolerances are exceeded the PM shall call "Speed" or "Sink Rate". The PF shall acknowledge this call and take corrective action.*
>
> *Corrective action is to be taken for all close to tolerance situations on approach.*
>
> ***Below DH, MDA or below 500 ft. AAL on Visual Approach.***
>
> *The PM will call airspeed and rate of descent using the Command Speed as the base value....*
>
> *Always emphasise descent rates in excess of 1,000 fpm.'*

Landing technique

The operator's operations manual describes three techniques for landing in crosswinds. They are the de-crab technique (with the removal of crab in the flare), the touchdown in crab technique and the sideslip (wing low) technique. The last of these is not recommended with crosswind components in excess of 20 kt. The commander recalled using the crab technique for the approach and not de-crabbing during the flare because of the sink rate immediately before touching down.

The operations manual states:

> *'Touchdown In Crab*
>
> *The aircraft can land using crab only (zero side slip) up to the landing crosswind limit speeds.'*

but adds:

> *'....touchdown in a crab only condition is not recommended when landing on a dry runway in strong crosswinds.*
>
> *On very slippery runways, landing the aircraft using crab only reduces drift toward the downwind side at touchdown and permits rapid operation of spoilers and autobrakes, because the main gear touchdown simultaneously. This may reduce pilot workload since the aircraft does not have to be de-crabbed before touchdown. However, proper rudder and upwind aileron must be applied after touchdown to ensure that directional control is maintained.'*

Go-around

The manufacturer approves go-arounds up to the point that reverse thrust is initiated after touchdown.

The operator advises crews that a touchdown beyond 2,500 ft from the threshold is undesirable and gives the commander the option to discontinue the landing and initiate a go-around if this is likely. The implication is that the go-around will be carried out before touchdown.

Summary - engineering

The evidence from the runway marks showed that B-KAG's right body MLG touched down around 193 m from the runway threshold with the aircraft tracking approximately 4° right of the runway heading and its CG around 15 m left of the runway centreline. Almost simultaneously, the No 4 nacelle contacted the runway and scrape marks indicated that it had around 7° left drift at the time. Shortly afterwards, the left wing MLG touched down. With the aircraft turning left and closing the runway centreline, this was followed, some 166 m after initial touchdown, by light runway contact by the No 1 nacelle and then by two momentary contacts by the No 2 nacelle.

No anomalies with the aircraft were found, with the exception of a fault in the No 2 Anti-Skid Valve. This probably allowed the No 2 MLG wheel to lock under braking, causing the tyre to wear through and rupture.

The manufacturer's simulations and modelling, based on the recorded flight data, indicated that the aircraft was responding correctly to crew control inputs and that the inputs were appropriate, although their magnitude may have contributed to the likelihood of a nacelle contact.

Discussion - operations

As forecast, the crosswind at Manchester Airport was outside the co-pilot's limit when B-KAG made its approach to land. However, the cloudbase was above 3,000 ft agl and the visibility was good. Having gone around from the first approach, following a windshear warning, the crew carried out a second approach. During it, they were advised by ATC that the aircraft ahead of them had landed. The aircraft in question was a different type and there was, therefore, no reason to link the success of its landing with the one B-KAG was about to make.

B-KAG's second approach, using a flap setting of 25° for the landing, appears to have been stable until the autothrust was disconnected at a height of 220 ft agl. The aircraft then drifted above the glideslope, before descending through it, during the course of which B-KAG lost 20 kt of airspeed in one second and then gained 23 kt in the next four seconds. The pitch attitude reduced from 2° above the horizon to 0° and then increased back to 4° nose-up for the landing. The rate of descent increased to a maximum of approximately 1,400 ft/min, resulting in a 'sink rate' warning below a height of 50 ft aal, but then reduced to about 300 fpm at touchdown. The aircraft landed at an airspeed of 163 kt.

When the aircraft rose above the glideslope, it also started to drift to the right of the localiser. The correction back on to the localiser coincided with the increase in rate of descent. The aircraft continued through the localiser, to the left of the extended runway centreline, and right roll was applied, reaching a maximum of 9.7° at touchdown. It was at that point that the underneath of No 4 engine nacelle struck the runway. The aircraft then rolled left, to a degree that was less than that required for a static aircraft to suffer ground contact with an engine. However, the dynamic behaviour of the wing probably accounted for the flexing that enabled the Nos 1 and 2 nacelles to touch the runway surface.

Following the clearance to land, the magnitude of the crosswind, as reported, reached a maximum of 28 kt. That was within the operator's specified crosswind limit for the commander. However, evidence indicates that there was significant variation in the strength and, possibly, the direction of the wind experienced by the aircraft. This was commensurate with the warning contained in the UK AIP entry for Manchester Airport, regarding the possibility of turbulence and large windshear effects when landing on Runway 23R in strong north westerly winds. It seems that the conditions were as challenging as any the commander had experienced since converting on to the B747.

An option existed for the commander to initiate a go-around and divert to an alternate destination where the surface wind conditions were more favourable for a landing. However, the conditions at Manchester Airport, the planned destination, were within the aircraft's and the commander's limits and it was only on landing that the aircraft rolled sufficiently for the nacelles to strike the ground, the earlier high rate of descent having been corrected to an acceptable level.

Although the commander employed the 'Touchdown In Crab' method, the aircraft had drifted from the right of the localiser to be 15 metres to the left of the runway centre line at touchdown. The roll to the right, which had developed just prior to touchdown, was countered with substantial left control wheel and left rudder pedal inputs. The combination of these, and the reactive forces on the aircraft during the landing, resulted in the subsequent roll to the left.

In this serious incident the landing conditions were challenging and very close to, or at, the crosswind limit for this operator. It appears from the recorded data that the last stage of the approach to land coincided with a change in wind direction and speed. There is no evidence that the flight crew were fatigued.

INCIDENT

Aircraft Type and Registration:	Boeing 757-204, G-BYAO
No & Type of Engines:	2 Rolls-Royce RB211-535E4-37 turbofan engines
Year of Manufacture:	1994
Date & Time (UTC):	22 October 2006 at 0835 hrs
Location:	Over North Sea/London Stansted Airport, Essex
Type of Flight:	Commercial Air Transport
Persons on Board:	Crew - 7 Passengers - 160
Injuries:	Crew - None Passengers - None
Nature of Damage:	None
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	43 years
Commander's Flying Experience:	11,000 hours (of which 6,000 were on type) Last 90 days - 206 hours Last 28 days - 39 hours
Information Source:	AAIB Field Investigation

Synopsis

Shortly after reaching cruise altitude on a scheduled passenger flight from Newcastle to Larnaca, a blue haze was observed in the passenger cabin. A precautionary diversion was made to London Stansted, where an emergency evacuation was carried out successfully. One cabin crew member initially had difficulty in opening the rear cabin doors, due to insufficient force being used.

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The blue haze could not be reproduced on initial investigation, which included engine ground runs. A planned post-maintenance proving flight was aborted during the takeoff roll when smoke entered the flight deck and cabin. Further investigation, which included ground runs at higher engine power settings, identified the source of the smoke to be the No 2 (right) engine. The cause was determined to be a fractured No 1 bearing floating seal ring, which had allowed engine oil to leak into the compressor airflow path and to be ingested into the bleed air system, which provides air to the cabin air conditioning system.

Two Safety Recommendations are made.

History of the flight

The aircraft was operating a scheduled passenger flight between Newcastle and Larnaca. The takeoff and climb were uneventful. Approximately five minutes after reaching its cruising level of FL 370 over the North Sea, the cabin manager (CM) contacted the flight crew via interphone to report a "haze" and an unusual smell in the cabin. She commented that the haze seemed worse in the rear of the cabin, but could not smell anything from her position at the front galley. On inspecting the cabin the commander saw a fine blue-grey haze, but could not detect any unusual smells. He returned to the flight deck, having requested that the CM report any change. She contacted him again shortly afterwards to advise that the smoke was getting worse.

The commander instructed the co-pilot to declare a 'PAN' to Maastricht ATC, with whom they were already in contact, to request a descent and direct routing to Stansted, approximately 100 nm distant. The CM then entered the flight deck to be briefed.

Having established the aircraft in a descent, the pilots commenced the Quick Reference Handbook (QRH) *'SMOKE OR FUMES – AIR CONDITIONING'* checklist. The first item on the checklist related to the use of oxygen masks and smoke goggles; these were not used initially, as no fumes could be detected on the flight deck at this time. In accordance with the operator's training, but not specified in the QRH procedure, the pilots paused for a few minutes between specific checklist items, to determine if the actions taken had been effective. When this checklist was complete the flight crew actioned the '*SMOKE OR FUMES REMOVAL*' QRH procedure.

Whilst descending through FL200 the aircraft was handed over to the London Terminal Control Centre (LTCC). The CM advised the flight crew that the haze appeared to be worsening and that some passengers were starting to feel unwell. Fumes were then detected on the flight deck, which prompted the pilots to don oxygen masks and declare a 'MAYDAY'. LTCC gave immediate clearance for a further descent and provided radar vectors to position the aircraft for an 8 nm final for Runway 23 at Stansted. The commander briefed the CM, giving the time to touchdown and stating his intention to stop on the taxiway after landing before determining if an evacuation was required. He also briefed ATC of his intentions. The passengers were informed via the Passenger Address (PA) system of the intention to divert to Stansted.

The landing was uneventful and the aircraft vacated the runway using the first available exit. When clear of the runway, but still remote from the terminal area, the commander brought the aircraft to a halt, as briefed, and set the parking brake. The CM reported via the interphone that smoke and fumes were still present in the cabin and as no airstairs were readily available, the commander chose to order an evacuation. He shut down the engines, checked that the aircraft was unpressurised and then gave the command over the PA system to evacuate.

The front right (R1) cabin door was not opened because the senior cabin crew member seated adjacent to it noted that few passengers were seated nearby, and those that were could evacuate via the front left (L1) door. The cabin crew member operating the rearmost doors first attempted to open the left rear door (L4), but was unable to do so. She then attempted to open the right rear door (R4) and had the same problem. She returned to the L4 door and, by pushing it "really hard" was able to activate the door power assist mechanism. The door then opened fully and the escape slide deployed automatically. She was then able to do likewise with the R4 door and passengers then used both rear exits. All the escape slides deployed satisfactorily on those doors that were opened.

After completing the shutdown checks the commander and co-pilot inspected the cabin to check that the evacuation was complete, before exiting via the L1 door.

Airport Fire and Rescue Service (AFRS) personnel marshalled passengers on the ground and directed them to waiting coaches. Some passengers received minor abrasions when descending the slides, but there were no other reported injuries.

Aircraft information

Cabin exits

The aircraft had eight cabin doors. These were designated L1 to L4 sequentially along the left side from front to rear and R1 to R4 for the corresponding doors on the right side. All eight exits were available for use in emergency and were equipped with inflatable escape slides and 'door assist' pressure bottles; the latter are designed to drive the door hinge mechanism to force the doors open during evacuation. 'Arming' a door (ie placing it in automatic mode) engages the activation mechanism for the escape slide and also arms the door power assist mechanism. When the door is opened, the door power assist operates and the escape slide is deployed automatically, allowing rapid egress of the passengers in an emergency.

Powerplant

The aircraft was powered by two Rolls-Royce RB211-535E4-37 turbofan engines. The engines supply compressed 'bleed' air to various aircraft systems, including the cabin pressurisation and air conditioning systems.

The left and right bleed air systems normally receive air from their respective engine compressor via a 'low stage' valve, positioned close to the forward end of the compressor. At lower engine power settings, the pressure available from the early stages of the compressor may be insufficient for the requirements of the air conditioning and other systems. A second, 'high stage' valve located in the later compressor stages then opens to supply higher pressure bleed air. The 'changeover' occurs at an Engine Pressure Ratio (EPR) of approximately 1.14 at sea level.

The engine lubrication system supplies pressurised oil to the main shaft bearings. Various methods are used to ensure that the air pressure external to the bearing chambers exceeds the local oil pressure, to prevent engine oil from escaping and contaminating the compressor air flow. If this should occur, oil mist can enter the bleed air system causing odour, fumes or smoke to enter the cabin via the air conditioning system. The forward (No 1) bearing on the low pressure (LP) shaft utilises a continuous cast iron seal ring as part of its sealing arrangement. Its purpose is to ensure that a positive air pressure gradient is maintained to prevent oil from escaping from the bearing housing.

Air conditioning system

Air conditioning is achieved by identical left and right air conditioning packs that are supplied with bleed air from the respective engines. Conditioned air from the packs flows into a common mix manifold where it is mixed with recirculated cabin air. The mixed air is then supplied to the passenger cabin. The flight deck is provided with conditioned air taken from the left pack duct, upstream of the mix manifold.

Each air conditioning pack is controlled via its own pack control rotary selector switch. The pack switches are normally set to the 'AUTO' position, which provides fully automatic control of the pack outlet air temperature. When a pack is operating, its pack control valve is modulated to control the pack airflow to a scheduled rate based on altitude. Selection of the pack control switch to OFF closes the pack control valve, shutting off the flow from the respective air conditioning pack.

Aircraft examination

Aircraft initial examination

Initial visual and borescope examination of the engines did not reveal any evidence of oil contamination in the compressor airflow path. The Boeing 757 Fault Isolation Manual (FIM) procedure for troubleshooting air conditioning smoke and/or fumes in the cabin was actioned. This culminated in engine ground runs being performed at EPR settings of 1.1 and 1.14, whilst selecting different bleed air sources and air conditioning packs, to try to isolate the source of the smoke/fumes. The latter engine power setting is just high enough for the high stage bleed valve to close, allowing air to be supplied via the low stage valve.

Examination of the 4L and 4R cabin doors did not identify any reason why the door operating forces should have been higher than expected.

The aircraft operator then planned to conduct a proving flight. During the takeoff roll, smoke appeared on the flight deck, causing the flight crew to abandon the takeoff at around 121 kt. Smoke was also visible in the cabin in the region of the L3 and R3 exit doors. At idle power no further smoke was generated on the flight deck.

Aircraft further examination

The aircraft was then subjected to further examination and testing to identify the source of the smoke; this included engine ground runs at higher power settings than previously used. This proved successful in generating smoke in the cabin and it was established that smoke was associated with the No 2 engine. After completion of these engine runs it was observed that the No 2 engine oil level indication was significantly lower than that of the No 1 engine.

Engine strip examination

The No 2 engine was removed and strip examined by the manufacturer under AAIB supervision. Pooling of oil was visible in the fan casing; this had emanated from the Intermediate Pressure Compressor (IPC) splitter fairing. Borescope examination revealed streaking of oil on and aft of the IPC Stage 5 compressor blades. When the fan assembly was removed, oil wetting of the internal bore of the LP compressor disc and the front of the LP shaft was visible. These are areas which are not normally lubricated. Removal of the LP shaft revealed that the No 1 bearing floating seal ring had fractured in two places.

The fractures were found to be orientated both radially and longitudinally, permitting the seal ring to open out in diameter. This had increased the clearance around the journal and created gaps in continuity of the seal ring, allowing oil to escape from the LP shaft front bearing housing. Examination by the manufacturer suggested that the cause of failure was tensile fracture, with a possible fatigue mechanism at the origin. It was considered that both fractures were initiated by the drag between the static seal ring carrier plates and the rotating LP shaft. The bore of the seal ring was uniformly worn and had no obvious areas of concentrated heavy rub. Magnetic particle inspection showed no other cracks to be present. The material properties, microstructure and hardness of the seal ring were found to be satisfactory. Its cross-sectional dimensions were in accordance with the drawing, with the exception of the outer diameter chamfers which were oversize, but this was not considered to be influential in this event.

The hours and cycles of the fan module did not place it near the lower or higher ends of the fleet experience. Records showed that only three other known seal ring failures had occurred in the operating history of the RB 211-535 engine series, which had completed over 52 million flight hours at December 2008. Given that this engine type has been in widespread use for about 20 years, a very large number of operating hours and cycles have been accumulated with only a small number of failures of this particular component.

Recorded data

The aircraft was equipped with a Flight Data Recorder (FDR) and Cockpit Voice Recorder (CVR) capable of recording a minimum duration of 25 hours of data and 30 minutes of audio respectively. Both were successfully replayed at the AAIB.

The FDR data indicated the following:

- The thrust setting on both engines at the time the in-flight haze in the cabin was reported was about 86% N_1, corresponding to an EPR of 1.6.
- During the initial troubleshooting after the diversion to Stansted, except for the time spent at idle thrust, the engines were predominantly operated at either 45% or 52% N_1, corresponding to EPRs of 1.1 and 1.14 respectively. The thrust setting for the No 2 engine momentarily reached 72% N_1 (1.29 EPR). This was the highest recorded during these initial engine runs.
- The engine thrust was stabilised at 89% N_1 (1.5 EPR) when the takeoff was rejected on the planned proving flight.
- During the subsequent troubleshooting the engines were operated at up to 89% N_1 (1.5 EPR).

The recorded data were consistent with the flight crew's recollection of the events during the incident, with the exception of the recorded positions of the air conditioning pack control valves. From shortly after engine start to the time the aircraft was shut down prior to evacuation, both left and right air conditioning pack control valves indicated they were in the open position. This was inconsistent with the flight crew's actions in accordance with the QRH, which required them to select each pack off in turn, to attempt to identify the source of the smoke or fumes. It was subsequently determined that the positions of the left and right pack control valves were incorrectly recorded due to a wiring error; this is believed to have occurred at aircraft build.

It was determined that the left and right pack control valve open and closed position signal wires had been erroneously connected at a point between the outputs from the left and right pack flow control cards and the inputs to the left and right bleed configuration cards. These signals should have been electrically isolated. This had the effect that when only one of the pack control valves was in the open position, both valves would indicate open, irrespective of the position of the other valve. Both valves would have also had to be in the closed position before a closed indication would have been provided. The wiring error would potentially result in the Flight Management Computer (FMC), Thrust Management Computer (TMC) and FDR being supplied with incorrect information. The aircraft manufacturer established that the operation of these systems would not have been significantly affected, with the exception of the FMC, where the performance calculations for single-engine operations would have given a maximum cruise altitude that was reduced by 200 ft. The aircraft manufacturer has since revised Chapters 22 and 34 of the Boeing 757 Aircraft Maintenance Manual to include tests to verify that the correct pack control valve position indications are provided to the thrust and flight management systems.

Additional information

Smoke/fumes removal procedures

The procedure actioned by the crew was contained in the operator's Quick Reference Handbook under the heading *'SMOKE or FUMES – AIR CONDITIONING'*; see Figure 1.

In order to identify a pack as a source of smoke, a pause is required after each pack control is selected OFF to determine if there has been any reduction in the amount of smoke or fumes. However, no such pause was specified in the procedure at the time of the event. The operator's pilots are advised during initial and recurrent training, which includes periodic revision of the procedure in a simulator, that a pause of some minutes may be required. In October 2007, Boeing revised the 757 QRH procedure to include the following statement after each pack selection to OFF:

> *'Wait 2 minutes unless the smoke or fumes are increasing'*

SMOKE OR FUMES – AIR CONDITIONING

Condition: A concentration of air conditioning system smoke or fumes is identified.

OXYGEN MASKS AND SMOKE GOGGLES (If required).. ON

CREW COMMUNICATION (if required)......... ESTABLISH

RECIRCULATION FAN SWITCHES (Both)............... OFF

[Removes fans as possible source of smoke or fumes. Stops recirculation of smoke or fumes and increases fresh air flow.]

APU BLEED AIR SWITCH.................................... OFF

If smoke or fumes continue:

ISOLATION SWITCH.................................... OFF

[Isolates left and right sides of bleed air system.]

RIGHT PACK CONTROL SELECTOR............ OFF

[Removes right side of air conditioning system as possible source of smoke or fumes.]

If smoke or fumes continue:

RIGHT PACK CONTROL SELECTOR....... AUTO

[Restores right side of air conditioning system.]

LEFT PACK CONTROL SELECTOR...........OFF

[Removes left side of air conditioning system as possible source of smoke or fumes.]

Do not accomplish the following checklists:

PACK OFF
RECIRCULATION FAN

If smoke or fumes are persistent:

Declare an emergency and plan to land at the nearest suitable airport.

Accomplish SMOKE or FUMES REMOVAL checklist on page 757.11.10.

CHECKLIST.. COMPLETE

Figure 1

QRH: Smoke or Fumes - Air Conditioning Checklist

Previous AAIB investigation

AAIB bulletin EW/C2005/08/10 reported on an incident to a DHC-8-402 registration G-JECE, on 4 August 2005. Soon after initiating a descent, an oily smell was noticed on the flight deck, followed almost immediately by a build-up of smoke in the flight deck and cabin. The cabin crew donned smoke hoods, which caused appreciable communication difficulties. The flight crew actioned the initial part of the smoke checklist procedure, declared an emergency and carried out a diversion. The source of the smoke was determined to be an oil leak from the No 2 engine, which had caused an oil mist to enter the cabin air supply.

Recognising the difficulty that flight crews often experience in identifying the source of smoke or fumes in the cabin, the bulletin contained the following safety recommendations to the European Aviation Safety Agency (EASA) and the US Federal Aviation Administration (FAA):

Safety Recommendation 2007-002

It is recommended that the EASA consider requiring, for all large aeroplanes operating for the purposes of commercial air transport, a system to enable the flight crew to identify rapidly the source of smoke by providing a flight deck warning of smoke or oil mist in the air delivered from each air conditioning unit.

Safety Recommendation 2007-003

It is recommended that the FAA consider requiring, for all large aeroplanes operating for the purposes of commercial air transport, a system to enable the flight crew to identify rapidly the source of smoke by providing a flight deck warning of smoke or oil mist in the air delivered from each air conditioning unit.

To date, the AAIB has not received formal responses to these recommendations.

Door operation in emergency

Appendix 1 to EU-OPS 1.1010 (Conversion and Differences Training) section (c) '*Operation of doors and exits*' contains training requirements for cabin crew members in respect of cabin door/exit operation. This states that:

'An operator shall ensure that:

(1) Each cabin crew member operates and actually opens all normal and emergency exits for passenger evacuation in an aeroplane or representative training device…'

In practice, cabin crew members will not often have the opportunity on aircraft to operate cabin doors and emergency exits with the door or exit armed. Training is therefore usually accomplished in a simulator. The initial force to open a door when its escape slide is armed (ie in automatic mode) may be greater than when it is opened in the disarmed or manual mode. It is therefore important that the door operating forces on the simulator are representative of the forces required on the aircraft. This issue was previously raised during the investigation of the accident to an Airbus A340-311, G-VSKY on 5 November 1997, when the AAIB made the following Safety Recommendation to the UK Civil Aviation Authority (CAA), the FAA and the Joint Aviation Authorities (JAA):

Safety Recommendation 2000-33

The CAA, FAA and JAA should review the requirements for public transport aircraft cabin door simulators used for crew training to require that they accurately simulate any non-linear characteristics of the associated aircraft doors and to require that full instruction is given to cabin crews regarding the door operating characteristics to be expected when operating the doors in an emergency.

In response to this recommendation, the CAA published Flight Operations Department Communication (FODCOM) 05/2001. This stated in part:

'Differences in door operating characteristics between actual aeroplane doors and the doors installed in cabin simulators can be of critical importance during an emergency evacuation, especially if an incorrect door operation procedure is used. In the worst case scenario, the crew member may not be able to effectively open a fully functional door or exit if incorrect or inadequate procedures have been specified in the Operations Manual and are repeated during training.

Consideration should be given to:

a. Retrospective modification of existing cabin simulators to address these potential problems.

b. Purchase of new cabin simulators to take into account the need for the equipment to accurately simulate all characteristics of aeroplane door operation.

c. Highlight anomalies between the operating characteristics of actual aeroplane doors and cabin simulator doors during training (e.g. by use of video) and in the Operations Manual. This is especially important where it is recognised that a cabin door simulator cannot, or does not, exactly replicate the actual aeroplane door operating characteristics.

Operations Manuals should be reviewed to ensure that information on aeroplane door operation is fully compliant with the procedures recommended by the relevant aeroplane manufacturer. In addition, operators should provide full instructions to their flight and cabin crew, based on information provided by the aeroplane manufacturer, regarding door operating characteristics that might be expected when operating an aeroplane door in an emergency.'

The CAA also submitted a proposal to the JAA Operation Steering Team (OST) that the requirements for door/exit training for cabin crew should be enhanced and clarified. The JAA OST agreed and the JAA Cabin Crew Steering Group was tasked with this. The rule material in JAR-OPS (now EU-OPS) 1.1010/15 and associated material was enhanced and formed part of Amendment 11 to JAR-OPS issued in August 2006. In light of these measures taken, the FODCOM was subsequently cancelled.

The current requirements for representative training devices are contained in document ACJ OPS 1.1005/1.1010/1.1015/1.1020. With respect to cabin exits, paragraph 2 (c) requirements state that such training devices should accurately represent the aeroplane in the following particulars:

'Exits in all modes of operation (particularly in relation to their mode of operation, their mass and balance and operating forces) including failure of power assist systems where fitted…'

Analysis

Source of haze/smoke

The origin of the haze and smoke in the flight deck and cabin was determined to be the No 2 engine. A fractured seal ring in the No 1 bearing on the LP shaft had allowed engine oil to leak into the compressor air path. The reason for the failure could not be determined but the seal ring contained no material defects and did not diverge significantly from design dimensions or geometry. The affected engine module was neither newly overhauled, nor had it accrued excessively high hours in relation to the remainder of the fleet of RB211-535 engines. As there have been only three recorded similar failures of this seal ring during the considerable service life of the large fleet, it was considered that modification action was not warranted.

Crew identification of source of smoke/fumes

Smoke or fumes in the flight deck or passenger cabin present the crew with a potentially hazardous situation, which requires prompt action. In this case the crew quickly decided that a diversion was the best course of action. They correctly identified the air conditioning smoke drill as being appropriate and initiated the actions. In this event, the procedure did not allow the crew to identify the source of the haze and thus it could not be isolated. The fact that they had promptly initiated the diversion meant that the aircraft could be landed as quickly as possible, before the situation became more serious.

The fact that such procedures have not always proved effective in identifying the source of air conditioning fumes and smoke prompted the AAIB to issue previous Safety Recommendations 2007-002 and 2007-003 to the EASA and FAA respectively. These recommended that large commercial transport aircraft be equipped with sensors that can provide the flight crew with a reliable indication of the source of air conditioning smoke/fumes. Had such equipment been fitted to G-BYAO, the crew may have been able to identify and isolate the source of the blue haze. Furthermore, this equipment would enable flight crews to more readily differentiate between air conditioning smoke and an actual fire within the aircraft.

When actioning the air conditioning smoke drills, the operator advised its pilots that a pause is required after each pack control is selected OFF, in order to determine if this has resulted in a reduction in smoke or fumes. Boeing has since amended the 757 QRH procedure to instruct flight crews to wait for two minutes after selecting each pack to OFF, to determine if the action has been effective in isolating the source of the smoke/fumes.

Troubleshooting procedures

The Boeing 757 FIM procedures employed during initial troubleshooting failed to reproduce the haze in the cabin that led to the diversion, as the engines were not run at a high enough power setting. The smoke did, however, manifest itself at the higher power settings used during the takeoff roll on the planned post-maintenance flight and during subsequent troubleshooting.

This suggests that the procedures contained in the FIM may not always be effective in reproducing smoke or fumes. The maximum EPR of 1.14 called for in the FIM is only sufficiently high for the high stage bleed valve to close and pressurizing air to flow via the low stage valve. This EPR value was demonstrated to be insufficiently high to exploit the seal ring failure. The following Safety Recommendation is therefore made:

Safety Recommendation 2009-041

It is recommended that the Boeing Commercial Airplane Company consider revising the procedures in the Boeing 757 Fault Isolation Manual to introduce a requirement for ground running at higher engine power settings, if initial testing fails to identify the source of smoke or fumes in conditioned air.

Boeing has responded to this safety recommendation, stating that the 757 troubleshooting procedures are being reviewed with a view to adding a requirement to conduct higher power engine runs when troubleshooting reports of smoke or fumes in the cabin and/or flight deck. A decision is expected by the end of the third quarter 2009.

Cabin door simulation

The CAA and JAA had taken previous measures intended to enhance cabin crew training in the operation of cabin doors and exits. The operational requirements state that training must be carried out either on the aircraft or in a representative simulator which accurately reproduces door and exit operating characteristics. However, in the light of this incident, it is not clear whether these measures remain effective in ensuring that cabin crew are aware of the different operating characteristics of cabin doors and exits when operated in the armed mode. The following Safety Recommendation is therefore made:

Safety Recommendation 2009-042

It is recommended that the European Aviation Safety Agency ensure that effective measures are in place for cabin crews to become, and remain familiar with, the different opening procedures and characteristics of aircraft exits in both normal and emergency modes of operation.

Conclusions

The source of the blue haze which caused the diversion and the smoke which resulted in the rejected takeoff was determined to be the No 2 (right) engine. A fractured floating seal ring on the No 1 bearing on the LP shaft had allowed engine oil to leak into the compressor airflow path; the oil mist was ingested into the bleed air system, which provides air to the cabin air conditioning system.

The flight crew actioned the appropriate QRH procedure, which required each air conditioning pack to be selected off in turn, but this was ineffective in identifying the source of the blue haze. In response to previous events of smoke and fumes in the cabin where the emergency procedures proved similarly ineffective, the AAIB issued Safety Recommendations 2007-002 and 2007-003 calling for large commercial air transport aeroplanes to be equipped with systems to indicate to flight crews the source of air conditioning smoke or oil mist.

Although the operator's flight crews were trained to wait for a period after selecting a pack to OFF, to establish if there is any reduction in the amount of smoke or fumes, the QRH did not reflect this requirement. In addition, no published information was available at the time which specified how long flight crews should wait after selecting a pack to OFF.

Although the evacuation was completed successfully, the cabin crew member responsible for opening doors 4R and 4L was initially unable to open the doors, being unaware that significant additional force would be required to open the door in order to activate the escape slide and door assist mechanisms.

The troubleshooting procedures provided in the Boeing 757 Fault Isolation Manual were, on this occasion, ineffective in identifying the source of the smoke/fumes, as they did not require engine ground runs at a high enough power setting for smoke to be generated.

ACCIDENT

Aircraft Type and Registration:	1) Boeing 777-236, G-VIIK 2) Airbus A321-231, G-EUXH
No & Type of Engines:	1) 2 General Electric GE90-85B turbofan engines 2) 2 International Aero Engine V2533-A5 turbofan engines
Year of Manufacture:	1) 1998 2) 2004
Date & Time (UTC):	27 July 2007 at 1900 hrs
Location:	London Heathrow Airport
Type of Flight:	1) Commercial Air Transport (Passenger) 2) Commercial Air Transport (Passenger)
Persons on Board:	1) Crew - 14 Passengers - 213 2) Crew - 9 Passengers - 102
Injuries:	1) Crew - None Passengers - None 2) Crew - None Passengers - None
Nature of Damage:	1) Left aileron and wing panel damaged 2) Vertical fin and fairing damaged
Commander's Licence:	1) Airline Transport Pilot's Licence 2) Airline Transport Pilot's Licence
Commander's Age:	1) 49 years 2) 46 years
Commander's Flying Experience:	1) 13,429 hours (of which 2,073 were on type) Last 90 days - 211 hours Last 28 days - 71 hours 2) 11,800 hours (of which 2,700 were on type) Last 90 days - 169 hours Last 28 days - 45 hours
Information Source:	AAIB Field Investigation

Synopsis

Boeing 777, G-VIIK, collided with a stationary Airbus A321, G-EUXH, whilst being pushed back from its stand at London Heathrow Terminal 4. Moments earlier, the Airbus had taxied behind the Boeing 777 towards its own stand, but had been unable to park because the electronic stand guidance had not been activated. It stopped short of the parking position, partially obstructing the taxiway behind the Boeing 777, and was not seen by the pushback crew until just before the collision.

The accident occurred primarily because the Boeing 777 pushback was not conducted in accordance with the aircraft operator's normal operating procedures and safe practices. A number of organisational issues were also identified which may have been contributory. Five Safety Recommendations are made.

Description of the accident

The two aircraft, operated by the same company, collided on a taxiway adjacent to London Heathrow Terminal 4. The Airbus A321, G-EUXH, had landed after an uneventful flight from Zurich and had taxied to Stand 431 under instructions from the Ground Movements Control 2 (GMC2) controller. As it did so, the crew of the Boeing 777, G-VIIK, were preparing to depart for Washington from Stand 429 (Figure 1). Another A321 in the same livery was parked on Stand 432, immediately to the left of G-EUXH.

As the Airbus approached its stand, the crew realised that the electronic Stand Entry Guidance (SEG) system was not switched on. This was because the operator's ground staff responsible for activating it had not yet arrived at the stand. The Airbus commander stopped his aircraft about 50 metres short of the intended parking position; it was aligned with the stand centreline, but with about half the aircraft protruding into the taxiway behind. He made a radio call to GMC2, to advise that the stand guidance was not illuminated, but the frequency was very busy and the call was not acknowledged. Whilst the commander informed the passengers and cabin staff that the aircraft was not yet on stand, the co-pilot attempted to contact his company on discrete frequencies to request that ground crew attend the stand.

About a minute after the radio call from the Airbus to GMC2, the crew of the Boeing 777 called GMC2 to request pushback from Stand 429, which the controller approved. During pushback, the Boeing 777's left wing collided with the Airbus' fin. The tug driver reported that he had seen the Airbus moments earlier and had applied the vehicle's brakes, but was too late to prevent the collision. The driver of a coach who was awaiting the Airbus' arrival took a photograph of the two aircraft in proximity (Figure 2).

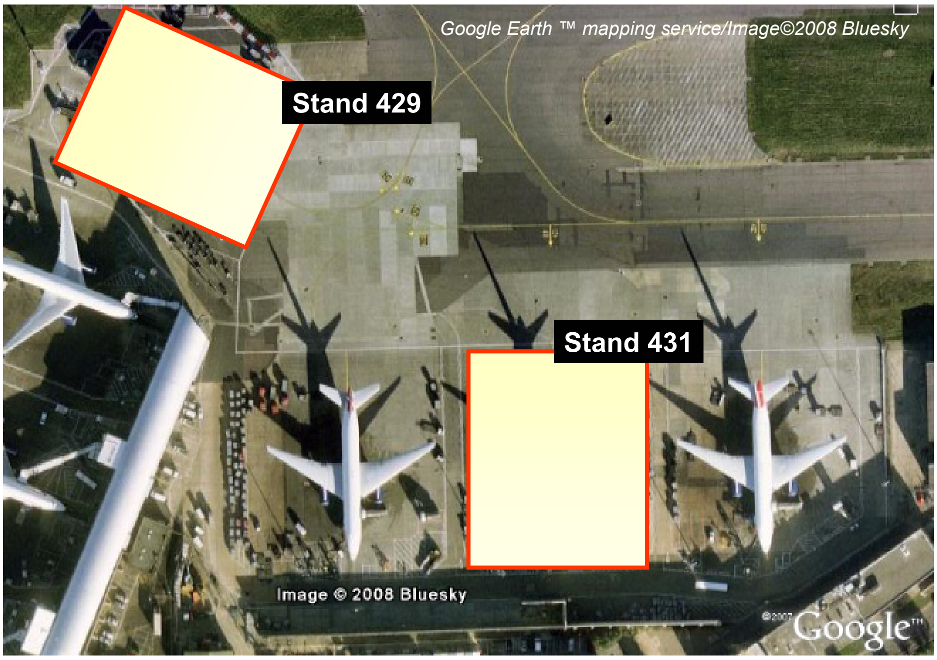

Figure 1

Layout of stands and taxiway in accident area

(Photograph courtesy of H Ghattaoura)

Figure 2

Aircraft in proximity at about the time of the accident

The collision was felt on both aircraft. The Airbus crew made a further call to GMC2, stating that their aircraft had been struck, but it, too, was not acknowledged. They then twice broadcast a PAN-PAN call, which was acknowledged after the second broadcast. The Boeing 777 crew also made a PAN-PAN call. The GMC2 controller took the appropriate actions, and alerted the airport emergency services. The tug was equipped with a radio capable of receiving and making transmissions on the GMC2 frequency, but it was not switched on prior to, or during, the pushback.

The Airbus remained stationary after the collision, but the Boeing's pushback crew immediately pulled the aircraft forward again, back onto Stand 429. The passengers on both aircraft reportedly remained calm and were disembarked via steps. There were no reported injuries.

Pushback crewmen's accounts

The Boeing 777 pushback crew consisted of two members: a tug driver and a headset operator, both employed by the aircraft operator. The driver had been employed for seven years as a headset operator and had qualified as a tug driver six months previously. The other crewman had worked for the operator for more than twenty years and, although he was acting as headset operator during the pushback, he was also an experienced tug driver.

Both crewmen gave their accounts of the accident. When they arrived at the Boeing 777, the headset operator established interphone communications with the aircraft commander, who informed him of an expected 15 minute delay. The tug driver removed the aircraft steps (the aircraft was on a remote stand) whilst the headset operator performed a 'walkround' check. Both crewmen then waited in the tug vehicle's cab.

When approved by the GMC2 controller, the commander informed the headset operator that the aircraft was ready for pushback. The headset operator asked the commander to release the aircraft's brakes, and the aircraft nosewheel was then raised by the tug in preparation for pushback. Although it was standard practice in accordance with the company's training for the headset operator to walk alongside the aircraft during pushback, he was still in the cab when the pushback commenced. He reported that he attempted to leave the cab, but had difficulty doing so because his headset lead had become entangled. Consequently, he had been in the cab for most of the pushback operation. The tug driver did not describe the headset operator having difficulty with the lead, but confirmed that the headset operator remained in the cab for most, if not all, of the pushback.

The tug driver described the limited view from the tug during pushback, and said he was concentrating on keeping the aircraft's main gear wheels about the taxiway centreline. He only became aware of the conflicting Airbus at a very late stage, as he was manoeuvring the aircraft tail to follow the taxiway. He applied the tug's brakes immediately, but the collision occurred before the aircraft/tug combination could be stopped. The headset operator then gave him instructions to pull the aircraft forward again.

The headset operator said that his attention had been directed towards the Boeing's right engine which was being started, and therefore away from the direction of the Airbus. He was unaware of the conflicting Airbus, and first realised that a collision had occurred when the Boeing's commander queried what had happened.

Flight crews' accounts

The Boeing crew reported an entirely normal pushback sequence until the point of collision. The Airbus commander was aware that his radio call to GMC2 had not been acknowledged, and intended to follow it up with a further call when radio traffic permitted. Meanwhile, he made a passenger announcement to the effect that the aircraft was not yet on stand. He was not immediately concerned about the aircraft's position, as it was on a relatively quiet part of the apron. The Airbus co-pilot spent some time attempting to make contact with his company on a discrete frequency but, as there was no answer on this, had to look up an alternative one.

Accident site

When the AAIB arrived on scene later that evening, Airbus A321 G-EUXH was still positioned on the centreline of Stand 431, about 50 metres short of the intended parking position. Boeing 777 G-VIIK had been towed back onto Stand 429 and was still attached to its tug. The rear half of the Airbus was encroaching into the taxiway (Figure 3). The main wheels were on the taxiway, two metres from the taxiway/stand demarcation line, and its tail extended 17 metres into the taxiway. The force of the collision had caused the Airbus' nose to move approximately two metres to the right. Tyre marks on the taxiway indicated that the aircraft had rotated around its left main landing gear.

Another Airbus A321, also in the operator's livery, was parked on Stand 432, adjacent to G-EUXH, prior to and during the accident.

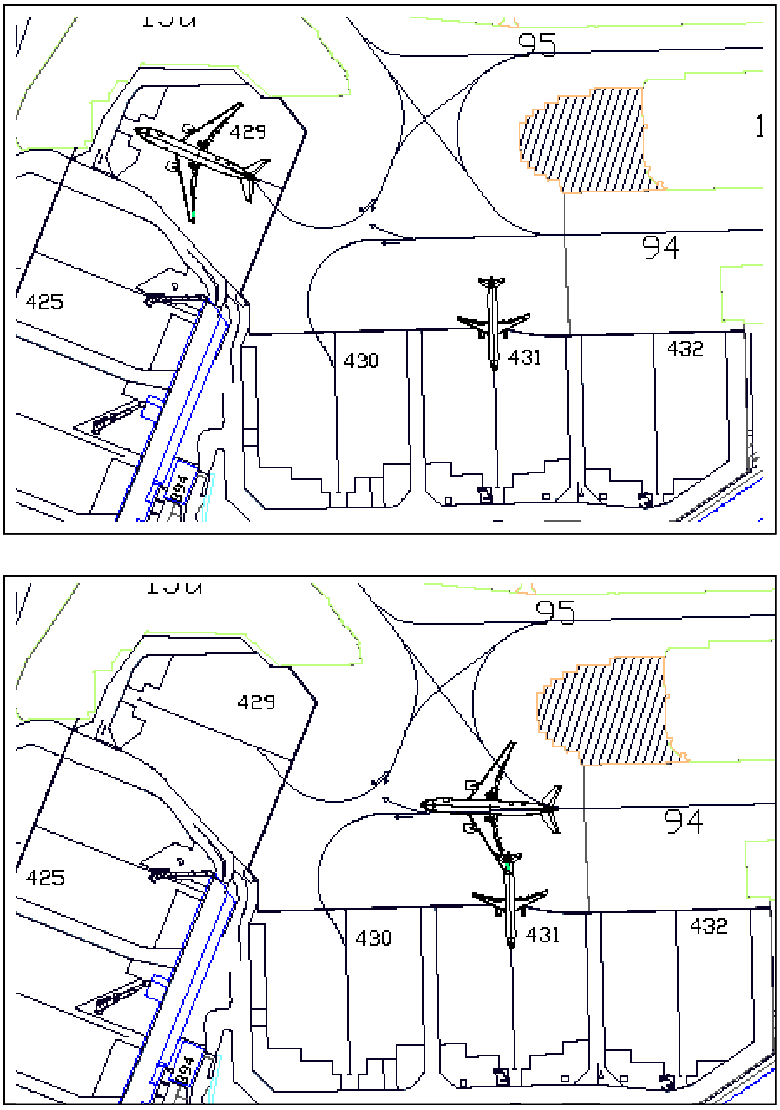

Figure 3

Positions of the two aircraft before and after pushback of G-VIIK (other aircraft not shown)

Aircraft damage

Boeing 777, G-VIIK

The collision caused significant damage to the Boeing 777's left aileron. A one metre long section of its surface, starting at a point 2.7 metres from the wingtip, had detached and become embedded in Airbus G-EUXH's fin lower fairing. A lower wing access panel and two aileron hinge-attachment points were also damaged. There was no other damage to the wing.

Airbus A321, G-EUXH

The fin and fin fairings were damaged; the majority of the damage was to the fin lower fairing, in which was imbedded the one metre long section of the Boeing 777's left aileron. The fairing immediately above this was also damaged and there was scuffing of the paintwork on the right side of the fin, extending some 1.85 metres aft of the fin front spar. Non Destructive Testing of the carbon composite material of the fin revealed some abrasion damage to the outer skin plys and damage to the inner back-face tape ply. Significant delamination was also evident on the carbon composite right hand flange, used to attach the lower fairing. There was no other damage, and an examination of the fin to fuselage attachment points did not reveal any secondary damage.

Towbarless tug vehicle

The tug vehicle was a Douglas TBL400 towbarless tug vehicle (TLTV). When maximum braking is demanded, the braking system applies the brakes progressively, limiting the loads to protect the aircraft's nose gear from damage. A TLTV pushing back an aircraft weighing 300 tonnes on level dry ground, at a speed of 4 mph, has a stopping distance of 14 feet (4.3 metres) under maximum braking. G-VIIK was calculated to weigh 240 tonnes at pushback. The TLTV was examined and found to be serviceable, and subsequent tests showed its braking performance to be acceptable.

During pushback, the tug vehicle travels in reverse: the driver's seat rotates through 180° to face aft. The passenger seat, on the left side of the cab, is fixed in a forward-facing position. Figure 4 illustrates how Airbus G-EUXH would have appeared at the start of the pushback, as viewed from each seat position in the tug.

Recorded information

Each aircraft was fitted with a solid-state Flight Data Recorder (FDR), Cockpit Voice Recorder (CVR) and a Quick Access Recorder (QAR).

One minute after G-EUXH had stopped short of Stand 431, the flight crew of G-VIIK transmitted their request for pushback from Stand 429. The GMC2 controller acknowledged, and after a short pause replied "(callsign) PUSH APPROVED TO FACE WEST".

According to ground radar information provided by National Air Traffic Services (NATS) at Heathrow, G-VIIK began pushback slightly more than two minutes after G-EUXH had come to a stop. As pushback started, the headset operator said to the commander "OK CLEAR TO START ENGINES WHENEVER YOU'RE READY". The headset operator made no mention to the commander of any difficulty he may have been experiencing, and there was no further headset communication until after the collision.

At 1900:30 hrs, three and a half minutes after G-EUXH had stopped, G-VIIK struck G-EUXH at a ground speed of about 4 kt. The CVRs for both aircraft confirm the

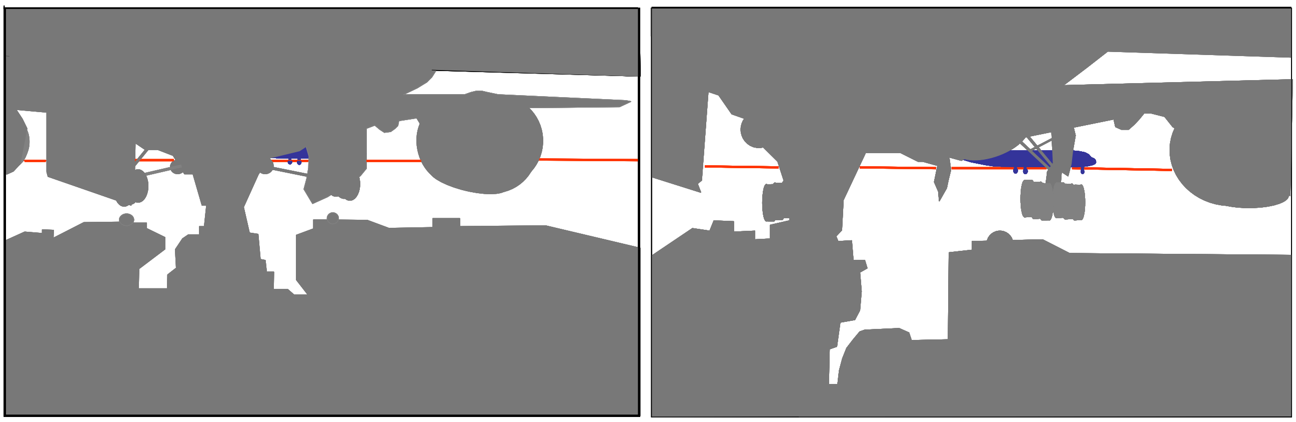

Figure 4

View from tug driver's seat (left) and view rearwards from the forward facing tug passenger seat (right) at start of pushback. Approximate position of Airbus G-EUXH shown in blue.

flight crews of each immediately recognised that a collision had occurred. The Airbus A321 FDR showed a lateral acceleration peak of 0.16g and an abrupt heading change from 182°(M) to 189°(M). The Boeing 777 FDR showed that the aircraft slowed to a stop within three seconds, covering a distance of around six metres.

After the collision, The Boeing 777 commander asked "WHAT DID WE HIT?" and the headset operator replied "AN AIRCRAFT GOING ONTO STAND FOUR THREE ONE..." It was evident from subsequent communications that the headset operator was surprised to find G-EUXH in the position that it was. As the Boeing 777 was being pulled back onto stand, the headset operator asked the commander "YOU WERE GIVEN PERMISSION TO PUSH BACK WEREN'T YOU?", to which the commander replied "AFFIRM".

Air Traffic Control

The GMC2 controller had started duty at 1230 hrs and had been at his position for 1hr 20 mins at the time of the accident, which was within prescribed limitations. When the Airbus commander made his "NO GUIDANCE STAND FOUR THREE ONE" transmission, the controller was busy rearranging the taxi sequence of other aircraft and did not hear the call. He later stated that, had he heard the call, he would have understood it to mean that the aircraft had not taxied onto stand.

The GMC2 position in the Heathrow control tower faces towards the accident area but is some 2,100 metres distant. An inspection of the controller's position showed that it was difficult to detect visually that an aircraft in the accident area was not fully parked on stand.

Surface Movement Radar (SMR) was only routinely used during periods of poor visibility. To avoid excess clutter, system software removed aircraft returns from the display when it sensed that an aircraft had moved onto a designated stand area, replacing the aircraft return with a diamond symbol. In this case, the Airbus had entered the stand area sufficiently far for it to be classified by the software as 'on stand'.

On receipt of the Airbus commander's PAN-PAN call, the GMC2 controller initiated an Aircraft Ground Incident and made an "ALL STATIONS STANDBY" broadcast. The PAN-PAN call from the Boeing 777 was made as the controller was reacting, so was not acknowledged immediately.

Pushback crew's responsibilities

Pushback and towing operations were functions of the operator's Aircraft Movements (ACM) department, part of its Heathrow Customer Services (HCS) department. Normal procedures were contained in an *Aircraft Towing and Pushback Manual* (ATPM). The ATPM included as a key safety point:

> *'When towing or pushing back either on the airfield or base areas, always be alert to the possibility of A/C[1] not fully positioned, incorrectly aligned on stand, and/or other obstructions. Never take for granted that physical clearance exists, even if you are given movement clearance by ATC.'*

The tug driver had overall responsibility for safety whilst undertaking pushback operations. The ATPM stated:

> *'Drivers are responsible for obstacle clearance for the A/C, ATC clearance instruction does not infer obstacle or wingtip clearance[2].'*

Footnote

1 Aircraft.

2 Incorporated into the manual in response to AAIB Safety Recommendation 2004-74, relating to towing accident of 23 March 2004 (AAIB ref EW/C2004/03/08).

In relation to the headset operator, an aide-memoire issued to staff by the ACM department stated that he was to *'...support and assist the team leader in his overall responsibility for safety'*. Included in the aide-memoire was the text:

> *'If you feel that to proceed would endanger you, others or risk an accident you must request the Team Leader / Tractor driver to stop and give him full reasons.'*

Concerning engine starting, the ATPM contained an explicit warning:

> *'Engine starting is not permitted until the engine to be started can be fully monitored by the person who has direct communication with the flight deck.'*

Supervisory staff within ACM stated that the stands in question were regarded as amongst the most straightforward stands for pushback at Terminal 4, and did not require specific instructions or procedures. It was also described as standard procedure for the headset operator to walk alongside the aircraft, normally on the outside of any turn. This would have been on the aircraft's left in this case.

Requirements for the use of radios in vehicles on the apron were set by BAA Heathrow Airport Limited (HAL), in accordance with recommendations in the CAA's Civil Aviation Publication (CAP) 642 *Airside Safety Management.* They required that drivers ensure their vehicle's radio was working, and tuned to the appropriate frequency, before entering the manoeuvring area, and thereafter that *'a listening watch must be maintained on the relevant GMC frequency/channel…'* This requirement was covered in ACM departmental training and testing material.

Ground crew working hours (local times)

Ground crew working hours were governed by regulatory requirements and additional requirements stipulated by the operator. Together, these limited the maximum consecutive days worked to nine, with two days off in any 14 day period. Double shifts were permitted, but consecutive double shifts were not. There was a maximum of 16 working hours in any 24 hour period, and a maximum of 72 working hours was permitted in one week. Normal shift hours for the ground crew were from 0615 to 1430 hours and 1430 to 2300 hours: actual shift beginning and end times were based on a staff clocking-in/out system.

The tug driver had exchanged shifts with a colleague, and had started work at 0614 hours on the morning of the accident, to work a double shift. His off-duty period prior to the shift was 7 hr 14 min and he had worked about 13 hr 45 min of the planned 16 hr 45 min shift when the accident occurred. The headset operator had worked an evening/night shift from 1400 hours the day before, to 0600 hours on the day of the accident, returning to work at 1810 hours. The tug driver had logged 55 hr 15 min of overtime in the month of July prior to the accident and the headset operator had logged 96 hr 30 min.

The pushback crew's working time records for the preceding four weeks showed that working hours rules had not always been adhered to. Clocking-in/out times did not always reflect overtime worked or, in some cases, normal shift periods, making it very difficult to track actual working hours for part of the time. From a combination of the planned roster, logged overtime and available clocking in/out information, it was calculated that both crewmen had worked in excess of the permitted 72 hours per week, for at least part of the four week period. One of the crewmen had worked four consecutive double shifts in the period. Actual shift start/finish times during this period were not always reflected in the clocking on/off record.

In March 2007, a new staff administration system was introduced, which was intended to assist and improve management of staff working patterns. Industrial relations and system confidence issues had delayed its operational start date, and at the time of the accident ACM line managers were still dependent upon the clocking-in/out system to monitor staff hours.

Stand Entry Guidance issues

HAL issued an Operational Safety Instruction (OSI) in July 2005, which detailed the responsibilities of airline and ground handling staff with regard to the operation of SEG systems. The OSI stated that switching on the SEG signified to a flight crew that the stand was unobstructed and ready for use. Concerning flight crew actions, the OSI stated:

> *'In the event of there being no activated SEG displayed upon approach to the stand, flight crews should contact Ground Movement Control to request marshalling assistance. Aircrew must not attempt to self-park if the SEG is not illuminated or calibrated for their aircraft type.'*

HAL's Airside Operations department commented that this was intended to mean that no part of the aircraft should cross the stand perimeter line. There were no specific instructions in the operator's Operations Manual to prohibit aircraft commanders from partially entering a stand area whilst awaiting activation of the SEG, although such an instruction was introduced after this accident.

The aircraft operator required a qualified person to confirm the stand area was safe to receive an aircraft before activating the SEG. The person normally carrying out this duty would be one of the operator's Turn Round Managers (TRM). In this case, the TRM allocated to G-EUXH had been delayed getting to the stand due to waiting for a Passenger Services Agent (PSA), as the two would normally travel to off-pier stands together. An internal investigation by the operator into an aircraft towing accident in February 2003 (AAIB report EW/G2003/02/09), in which an aircraft stopped short of stand whilst awaiting SEG illumination, made a number of recommendations, including:

> *'Review failure of Dispatcher to switch on SEG system in time for arriving aircraft. Modify process as required and/or introduce contingency plans.'*

This recommendation was signed off by the operator's Ground Safety Board, but the problem of late SEG activation persisted. A data gathering exercise carried out by the operator between November 2006 and August 2007 produced a total of 1,630 crew reports of delays caused by SEG not being switched on, or by stands being blocked by ground equipment. There were 217 such reports in the 14 days after the subject accident.

The operator subsequently proposed a number of measures to address the problem, including increased numbers of TRMs, a measure that was due to take full effect by September 2007. The arrangement whereby the TRM would wait for the PSA before proceeding to the stand was stopped, and mobile 'chocks and power' teams were introduced to help alleviate the problem. Engineers were also being trained to activate the SEG if required, and the Operations Manual was amended to ensure flight crews did not stop their aircraft partially on stand.

Operator's Safety Management System

Hazard analysis and risk assessment

A hazard analysis and risk assessment for the pushback operation at Heathrow had been conducted by the ACM department in May 1997. It was reviewed annually, most recently in March 2007. The hazards considered were:

> *'Vehicle traffic routes / pedestrians*
> *Noise*
> *Engine ingestion'*

The protective control measures in force were identified as:

> *'Personal protective equipment*
> *Safe systems*
> *Training / instruction*
> *Full training of HAL operational byelaws'*

A further, separate, risk assessment pertaining to the pushback operation was held locally within ACM. The hazards identified by this were in relation to the health and safety of personnel conducting the pushback operation, rather than the operation as a whole. In this case, most control procedures were in effect delegated to HAL and NATS Heathrow, with only *'training procedures'* residing within the operator's direct influence.

Following the towing accident of 2003, the internal investigation made the following recommendation:

> *'Include the hazards of aircraft stopped short of stands in all pushback/towing risk assessments.'*

The recommendation was signed off by the operator's Ground Safety Board, but was not adopted. However, the ATPM did warn ground crew to be alert to the possibility of aircraft not fully positioned, incorrectly aligned on stands, and/or other obstructions.

Safety Management System reviews

Following a further towing accident in March 2004 (AAIB report ref EW/C2004/03/08), an internal investigation by the operator's safety department recommended a full and detailed review of all elements associated with the safe movement of aircraft by the operator's Heathrow Customer Service department. The report also recommended that the operator should:

> *'Undertake a review of recommendations resulting from previous accidents ... to ensure full and proper closure. The review should also consider whether the recommendations have been effective and ensure that a robust recommendation tracking system is in place.'*

The recommended review took place in September 2004. Improvements were noted in several areas and the operator conducted a number of risk assessments in regard to complex pushbacks and where high risk was identified. However, despite specific mention, a risk assessment of aircraft stopping short of stands was not performed.

Safety awareness training

The operator had run a recurrent safety awareness training course for ACM staff, but this was discontinued in February 2003 due to resourcing issues. The operator's internal report on the 2004 towing accident recommended that safety training be reintroduced, and the subsequent SMS review made the same recommendation. At the time of this accident recurrent safety training, including the review of past events and sharing of knowledge for ACM staff, had not yet been reinstated.

'Rampsafe' behavioural risk improvement programme

The operator introduced its 'Rampsafe' programme in 2005, intended to identify 'at risk' behaviours in the airside environment. The programme consisted of observations of ramp activities by appropriately trained supervisory staff, who would complete a simple checklist and debrief staff on the spot if any unsafe activities were seen. In the seven months to the end of July 2007, 443 Rampsafe checklists were returned. There was no evidence of headset operators remaining in the cab during pushback operations.

Analysis

Pushback crew's actions

The headset operator was required to be in a position to monitor the pushback area and the engine being started. These responsibilities were listed in the applicable publications and aide-memoires, and were principles which both crewmen had worked to for a number of years. Both would have known that to commence pushback with the headset operator still in the cab of the tug was not in accordance with their operating procedures.

If the headset operator had intended to leave the cab before pushback started, he could have done so. Since it was he who gave the tug driver the instruction to start the pushback, he could have delayed the instruction until the tangled headset lead had been dealt with. Similarly, he gave the commander clearance to start engines before the commander had requested it, which also indicates that the headset operator was content with his situation at that stage. He remained in the cab as the right engine was started, where his view of the engine was hindered by the seating arrangement and the aircraft structure, preventing him from adequately monitoring it, as he was required to do. The headset operator's actions, and the lack of mention by the tug driver of any difficulty with the headset, would suggest that any problem with the headset lead was minor, and of limited impact. Therefore, it was not a contributory factor.

As the tug driver stated (and Figure 4 illustrates), the view behind the aircraft from his position was very restricted, so he was dependent to a large extent upon the headset operator warning of obstacles or hazards that may not be visible to the driver. The driver would have been aware that the headset operator's continued presence in the cab was contrary to procedures and would affect his ability to identify possible hazards. The driver had overall responsibility for the safety of the aircraft and ground crew during the pushback; he could have delayed or halted it at any time, but he did not.

It was a requirement of the airport authority and the aircraft operator that the tug's radio be used to monitor the appropriate GMC frequency. As the radio was switched off, there was no possibility of the ground crew hearing any of the radio calls that could have alerted them to the developing situation.

Towing the Boeing 777 forward after the collision ran the risk of exacerbating the damage to both aircraft, and could potentially have hindered the accident investigation. Two experienced crewmen were involved, which highlights the need for a thorough grounding and regular recurrent training in accident and emergency procedures. The ATPM did not contain generic post-accident procedures. and the lack of recurrent safety training meant that there was limited opportunity to review such procedures in a formal training environment.

The following Safety Recommendation is therefore made:

Safety Recommendation 2009-034

It is recommended that British Airways PLC should include generic post-accident and emergency procedures for ground handling staff in its *Aircraft Towing and Pushback Manual*, and include such procedures in recurrent safety awareness training.

Human factors

The headset operator was the older of the two crewmen, and had many years of experience in pushback and towing operations. He was described as being amongst the longest serving crewmen in the department. Although it is possible the tug driver condoned the headset operator's actions, it is more probable that a significant adverse 'authority gradient' existed, which in effect caused the tug driver to defer to the older and more experienced man.

The headset operator's post-accident comments heard on the CVR were spoken at a time of obvious stress. However, they indicate a lack of awareness that an ATC approval to pushback an aircraft did not imply that obstacle or wingtip clearance was assured. Knowledge of this fact was fundamental to a safe pushback operation, and it had been included in the ATPM after being identified as a factor in a previous accident. The headset operator's incorrect assumption that pushback approval offered a measure of protection is likely to have influenced his actions, and was therefore a contributory factor.

At the time of the accident there was an Airbus A321 aircraft, in the operator's livery, parked on Stand 432. This was on the far side of Stand 431 when viewed from the tug position. The ground crew would almost certainly have seen this aircraft earlier, though it would not have been a factor for the pushback. With G-EUXH stopped short of Stand 431, it would have appeared to an observer in the tug cab to be in about the same relative position (albeit closer) as the aircraft on Stand 432, and probably partially obscured the aircraft actually parked there (Figure 5). It is conceivable that one or both of the ground crew had seen G-EUXH from the tug's cab

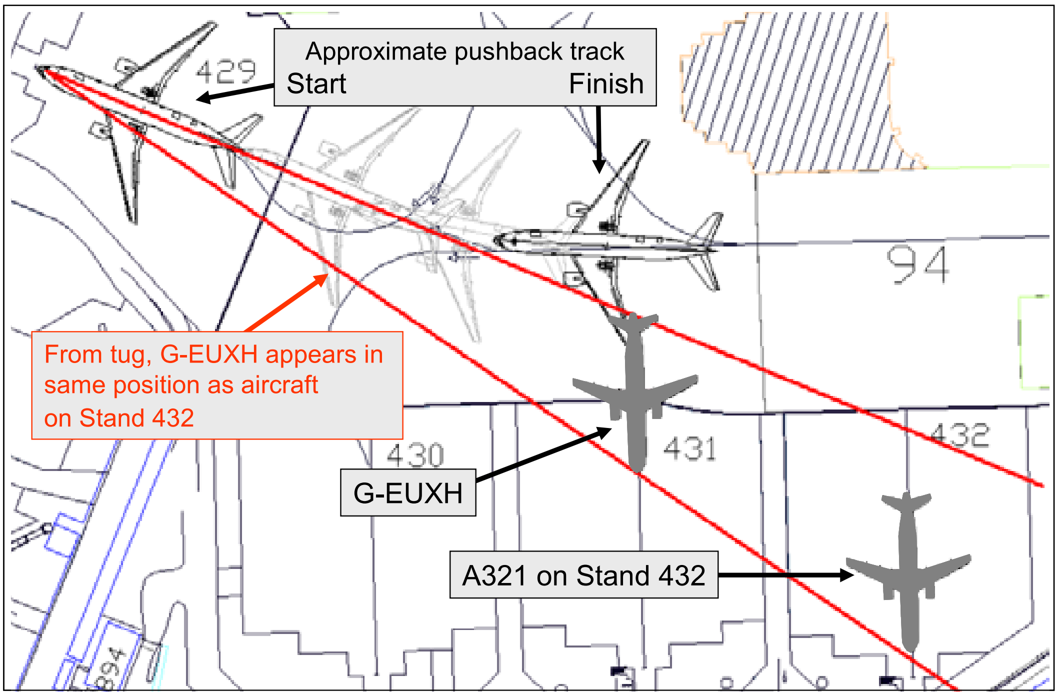

Figure 5

Relative position of the two Airbus aircraft as viewed from the tug cab before pushback, but believed it to be the aircraft they had seen earlier on Stand 432, which for all practical purposes was identical to G-EUXH. If so, this illusion would have persisted until shortly before the accident.

Working hours issues

The tug driver had been off-duty for 7 hr 14 min before clocking in again at 0614 hrs local time. Even allowing for a short commute, it is unlikely that he had the opportunity to sleep for more than six hours before starting a shift that would last 16 hr 45 min. The accident occurred 13 hr 46 min after the driver started work. The headset operator had been on shift a relatively short while and his previous rest period was just over 12 hours, but this had been taken during the daytime, which may have affected the quality of his sleep. Considering the irregular and un-rostered shift patterns, levels of overtime, and duty times immediately preceding the accident, the possibility that fatigue played some part in the ground crew's performance cannot be discounted.

Line managers in the ACM department were dependent upon the clocking-in/out system to monitor staff hours. However, the system made this task difficult, and records for the preceding four weeks showed that working hours rules had not always been adhered to. The crewmen themselves also had a responsibility to ensure that their working hours did not breach the rules, but the evidence indicated that they did not exercise this responsibility. The records showed that each had worked considerable overtime in the previous four weeks, and one of the crewmen had worked four consecutive double shifts, which was not permitted.

The following Safety Recommendation is therefore made:

Safety Recommendation 2009-035

It is recommended that British Airways PLC should ensure that an effective and robust system is in place to monitor and manage the working hours of its Heathrow Aircraft Movements staff, ensuring compliance with applicable working time rules and agreed practices.

British Airways stated that the staff administration system was scheduled to be fully implemented by end of April 2009.

Safety Management System

Since the 2003 review of safety management within HCS, a number of improvements were made. These included the 'Rampsafe' initiative, which was generally well-received and had produced positive results. Nevertheless, some of the contributory factors to this accident are largely unchanged from those of earlier accidents and, for the most part, fall under the direct control of the operator.

The risk assessment of the pushback operation did not adequately identify or address the hazard of other aircraft stopped short of stands; this was highlighted as an area of concern in 2003, and was the subject of a specific recommendation. Recommendations to review risk assessment data were made in 2002 and 2004, but there was no indication that this had been done. The operator's SEG problems at Heathrow were commonplace at the time of this accident, despite a 2003 recommendation to address the issue.

The following Safety Recommendation is therefore made:

Safety Recommendation 2009-036

It is recommended that British Airways PLC introduce a process to review recommendations arising from formal corporate safety investigations, to ensure closure and to consider whether they have been effective.

British Airways stated that a formalised tracking system of all corporate safety investigation incident recommendations was introduced in early 2006, but this did not retrospectively review past investigations. Hence a review of recommendations arising from previous incidents, as referred to in this bulletin, would not have been carried out. In 2007 further improvements were introduced, with the Corporate Quality department conducting the reviews instead of the original safety investigator. Additionally, all corporate safety recommendations now require metrics to be added to enable an objective measure of the effectiveness to be made.

Training

Training was listed as a control measure in the operator's risk assessment for the pushback operation, yet ACM staff recurrent safety awareness training including the review of past events and sharing of experience was withdrawn in 2003. Despite a call for it to be reinstated after the 2004 accident, and again as part of the 2004 SMS review, such training was still not in place at the time of this accident. Such training typically draws on lessons from past accidents and incidents as well as reinforcing the need for adherence to procedures and improving awareness of hazards. As such, the operator's decision to discontinue such training was considered to be a contributory factor in this accident.

The following Safety Recommendation is therefore made:

Safety Recommendation 2009-037

It is recommended that British Airways PLC reinstate recurrent safety awareness training for its Aircraft Movements staff.

Airbus G-EUXH

Neither HAL's OSI nor the operator's procedures appeared specifically to prohibit the Airbus commander from partially entering the stand area to await SEG activation. Given the number of occasions that the operator's aircraft were prevented from parking through late activation of SEG, there would have been an understandable desire on the part of flight crews to reduce potential congestion by entering the stand part-way, which had become a common practice.

Were an aircraft commander to be specifically prohibited from partially entering a stand area without SEG, the subsequent risk of collision would be reduced, as the aircraft would in most cases physically block the taxiway and present a much more obvious hazard. Although HAL's OSI had intended to convey this message, there was a degree of ambiguity which was passed on in the operator's guidance to its flight crews.

The following Safety Recommendation is therefore made:

Safety Recommendation 2009-038

It is recommended that Heathrow Airport Limited reissue the requirements of Operational Safety Instruction OS/20/05, specifically prohibiting aircraft commanders from allowing any part of their aircraft to enter a stand area if the Stand Entry Guidance system is not activated.

The Airbus commander's radio call to GMC2 was not acknowledged, therefore it had to be assumed that the controller had not heard it. The busy radio situation prompted the commander to make the call brief, but its brevity may have been the reason it was not heard. Had the transmission been made as a direct request for action on the part of the controller (eg to request marshalling assistance, as directed in HAL's OSI) rather than as an information call, it may have been more likely to attract his attention.

Air Traffic Control

It is unlikely that the GMC2 controller could have determined visually that G-EUXH presented a threat to G-VIIK. The approval he issued did not imply that obstacle separation was assured, nor did it relieve the pushback crew of the responsibility for collision avoidance, a responsibility which was emphasised in ACM departmental documentation. The GMC2 controller's actions were therefore not contributory to the accident.

Conclusion

The accident occurred primarily because the Boeing 777 pushback was not conducted in accordance with the aircraft operator's normal operating procedures and safe practices. Organisational factors which may have contributed to the accident included: the withdrawal of recurrent safety awareness training for ground handling staff, late stand guidance system activation issues, and incomplete risk assessments for towing and pushback operations.

INCIDENT

Aircraft Type and Registration:	DHC-8-402 Dash 8, G-JECY
No & Type of Engines:	2 Pratt & Whitney Canada PW150A turboprop engines
Year of Manufacture:	2007
Date & Time (UTC):	15 January 2009 at 1000 hrs
Location:	Stand 8L, Birmingham Airport
Type of Flight:	Commercial Air Transport (Passenger)
Persons on Board:	Crew - 4 Passengers - 70
Injuries:	Crew - None Passengers - None
Nature of Damage:	Inboard right tyre tread slightly damaged.
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	54 years
Commander's Flying Experience:	7,800 hours (of which 1,700 were on type) Last 90 days - 185 hours Last 28 days - 50 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot and further investigation by the AAIB

Synopsis

Towards the end of the pushback, a loud noise on the ground crew interphone caused the ground crewman to remove his headset and revert to hand signals. The captain was distracted by the breakdown in communication and believed he did not apply the parking brake before the tug was disconnected. The aircraft rolled backwards and came to rest with the right main wheel off the edge of the apron.

History of the flight

G-JECY was on Stand 8L at Birmingham Airport prior to a flight to Glasgow and the flight crew were given permission to push back. Prior to commencement of the pushback there had been various communications between the ground crew man and the commander on the intercom, one of which had coincided with the commander's public address to the passengers. There was loud interference on the ground crew intercom just before the pushback was complete. The ground crew man managed to stop the interference once but it reoccurred loudly and continuously, which the flight crew found distracting. The ground crewman took off his headset, which he showed to the captain, and indicated that he would use hand signals. The captain's and ground crew man's recollection differed with regard to the series of hand signals that followed. The ground crew man remembered signalling the captain to apply the parking brake whereas the captain did not recall seeing the signal. The result was that the parking brake was not applied before the towbar was disconnected.

The tug moved away from the aircraft and the flight crew began their after start actions and checklist. As the checks were being carried out, the captain noticed the aircraft moving backwards slowly. He decided not to brake hard in case the aircraft tipped backwards but applied power to arrest the movement. The aircraft stopped in what the flight crew believed to be the indent of the rain gutter at the edge of the apron. The crew requested taxi clearance following which the captain applied power to move forward. The aircraft turned to the right because the right mainwheel had, in fact, rolled over the edge of the apron and was now unable to climb back over the lip. The captain reduced power and applied the parking brake, following which he shut down. The passengers disembarked and returned to the terminal by bus.

The captain believed that the breakdown in communication with the ground crew at completion of the pushback and the resulting distraction from his normal task and procedures, led him to forget to apply the parking brake.

ACCIDENT

Aircraft Type and Registration:	Tornado GR4A, ZA 371
No & Type of Engines:	Two Rolls-Royce RB 199 Mk 103 turbofan engines
Date & Time (UTC):	5 August 2008 at 1556 hrs
Location:	Newcastle Airport
Type of Flight:	Military
Persons on Board:	Crew - 2 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	Damage to nose landing gear and forward underside panels
Commander's Licence:	Qualified Service Pilot
Commander's Age:	28 years
Information Source:	AAIB Field Investigation

Synopsis

The aircraft diverted to Newcastle Airport following a bird strike. During landing, an electrical connection in the right engine reverse thrust control system became intermittent, producing random oscillations of the engine's reverse thrust buckets. The fault was such that it was not clearly indicated to the crew until the aircraft had travelled a considerable distance along the runway and the pilot did not take the appropriate action of retarding the right power lever. With full dry power selected on both engines throughout the landing roll, there was thus a considerable forward component of thrust, and the pilot was unable to stop the aircraft before it overran the runway end.

Background to the investigation

The accident was the subject of a full investigation by a Royal Air Force Board of Inquiry (RAF BoI), assisted by the AAIB under the terms of a standing agreement. Additionally, as the accident occurred at a civilian airport, the Chief Inspector of Air Accidents ordered an AAIB Field Investigation under the provisions of the *Civil Aviation (Investigation of Military Air Accidents at Civil Aerodromes) Regulations 2005*.

History of the flight

The aircraft was the second of a pair of Tornado aircraft, engaged on a routine squadron sortie. It was crewed by a pilot and a weapon systems operator (WSO). The former was an experienced Tornado pilot, who had recently completed an instructional tour on Hawk aircraft. The WSO had recently completed operational training and had joined the squadron a month earlier.

The aircraft was manoeuvring about 40 nm north-west of Newcastle when it suffered a bird strike. Recorded flight data showed that it occurred as the aircraft was accelerating through 440 kt, at a height of 430 ft above ground level (agl), parameters which were within the authorised limits for the exercise. The pilot climbed the aircraft to a safe altitude, whilst the crew of the lead aircraft performed a visual inspection. This revealed damage to the Forward Looking Infra-Red (FLIR) sensor, which is mounted in a blister below the forward fuselage. Considering the possibility that an engine may also have suffered damage, the crew elected to divert to Newcastle Airport for a precautionary landing. There was some discussion between the pilot and WSO about the suitability of Newcastle. It was agreed that the airport was a suitable diversion, although there was no discussion about the runway length or its configuration.

Before starting the recovery to Newcastle, the crew carried out a low-speed handling check, using a forward wing sweep/MID flap configuration in accordance with recommended procedures. An approach speed of 175 kt was calculated (based on the aircraft's mass), which was expected to correspond to an approach Angle of Attack (AoA) of 10 units[1]. This was considerably faster than normal landing speeds, because of the reduced flap setting (MID rather than DOWN) and higher than normal landing fuel load. The aircraft was capable of jettisoning fuel, but this was not discussed by the crew.

Although both engines appeared to be operating normally, the crew planned for a precautionary single-engine approach profile, to cater for a possible loss of engine thrust during the approach. However, there was no discussion about the stopping capability of the aircraft should an engine actually fail before landing, which would leave only half of the reverse thrust capability (reverse thrust being the main aid to deceleration after landing).

The crew informed Newcastle Air Traffic Control (ATC) of the damaged FLIR and requested a remote parking location, deciding there was a potential, although small, risk to personnel from damaged internal components. Runway 07 was in use, with light winds; the visibility was greater than 10 km, with scattered cloud cover at 2,000 ft, and rain showers in the vicinity. Once the aircraft had commenced recovery to Newcastle, the lead Tornado climbed from the area to return to base.

At about 5 nm from touchdown, ATC issued landing clearance and passed a surface wind of 120º(M) at 5 kt. The aircraft touched down 90 m (295 ft) beyond the runway displaced threshold, at 180 kt; the lift dump system operated normally and the pilot selected reverse thrust. He reported that cockpit indications of correct reverse thrust system operation were obtained, before he advanced the power levers to the maximum 'dry power' (non-reheat) position.

Most eye-witnesses on the ground later reported that the aircraft appeared fast during landing and did not slow down on the runway as quickly as they had expected. As the aircraft approached the runway mid-point, the pilot became aware of the poor deceleration and saw flickering of the cockpit indication of right engine reverse thrust. He selected the system to OVERRIDE and started wheel braking (on the Tornado, the wheel brakes are normally only used towards the end of the landing roll). As he did so, a red REV warning caption illuminated on the Central Warning Panel (CWP), accompanied by an audio alarm tone which indicated that a fault had occurred which affected the deployment of an engine thrust reverser. Both power levers remained at the maximum dry power setting throughout the landing roll.

Although the aircraft decelerated at an increased rate with wheel brakes applied, the pilot realised that it might

Footnote

[1] Approach and landing in the Tornado, as with many fast jet aircraft, is flown primarily with reference to AoA.

still overrun the runway and warned the WSO to this effect. The aircraft left the paved surface at 33 kt ground speed, still with both power levers at maximum dry power and with reverse thrust selected. The aircraft's nose landing gear dug into the soft ground and collapsed rearwards. The aircraft came to a stop in a nose-low attitude, its nose 30 m beyond the paved surface. The pilot shut down both engines and ordered an emergency ground egress: the WSO left the aircraft first, 36 seconds after it came to a stop, followed 17 seconds later by the pilot. Three rescue appliances of the Airport Fire Service (AFS) had already taken up standby positions adjacent to the runway, so were on scene shortly after the aircraft came to a stop. There was no fire.

Airport operations were suspended for about 90 minutes, before recommencing with reduced runway operating distances. Normal operations were resumed at 0622 hrs the following morning, after the aircraft had been removed from the Runway 07 overrun area.

Initial aircraft examination

When first examined by the AAIB, the aircraft had been salvaged and was resting on a 'low loader' vehicle with landing gear retracted. This prevented any more than an external examination. In particular, access doors on the underside of the fuselage could not be opened. The aircraft showed clear evidence of damage from the overrun. The nose gear leg had been displaced aft to beyond the normal angle as the result of an overload failure of the lug attaching the drag link to the aircraft structure. The right-hand thrust reverser bucket was seen to be not fully flush with the surrounding structure, suggesting incomplete retraction and stowage but the left reverser bucket appeared fully retracted and stowed.

When the aircraft was placed on trestles and jacks, a more detailed examination was possible, as well as functional testing of the reverse thrust system, Testing utilised an external pneumatic power source. Following the tests on the left reverser, an electrical connector, designated C3, joining the engine wiring loom to the solenoid powering the air selector valve for the reverse thrust system on the right engine, was seen to be incorrectly secured. The screw cap of the harness connector was seen to be positioned at the outer end of the threaded section on the solenoid housing. On further examination, it was found to be resting against the end of the threaded portion, held in position by the geometry and rigidity of the harness.

Recorded information

Recorded information was available from: radar and radiotelephony (R/T) data from Newcastle Airport; various recording equipment on board the aircraft; conventional and Forward-Looking Infra-Red (FLIR) video from cameras mounted on the AFS rescue vehicles, and Newcastle Airport's CCTV security cameras. The information in the following paragraphs was derived from this recorded information.

During final approach, there was some discussion on a discrete frequency between the pilot and the crew of the lead Tornado (which was by now climbing from the area) about the damaged IR and associated after-landing procedures. As the aircraft descended through 700 ft agl, the pilot tasked the WSO with consulting the Flight Crew Checklist (FCC) to see if there was a procedure for FLIR damage, which there was not. Further discussion between the pilot and the lead aircraft continued intermittently until ZA 371 was less than 200 ft above the runway.

Lift dump deployed one second after touchdown and was verbally confirmed by the WSO. There was no recorded data concerning the cockpit selection of reverse thrust, but both engine power levers were advanced from idle to maximum dry power between two and three seconds after touchdown. Both engines responded normally and reached commanded power about seven seconds after touchdown.

A memory module in the right engine control unit stored reverse thrust bucket position data, recorded at half second intervals. The two positions capable of being recorded were 'fully deployed' and 'not fully deployed', the signal for both coming from the same 'deployed' sensing microswitch that signalled correct reverser deployment in the cockpit. The data showed that the right reverse thrust buckets had not reached a fully deployed state at any stage of the landing roll. The left engine was not equipped with a memory module, so there was no recorded on-board data concerning the actual position of the left thrust reverser.

Thirteen seconds after touchdown, the aircraft had slowed to 140 kt, with slightly more than 1,067 m (3,500 ft) of LDA remaining. Between touchdown and this point, three very brief sounds were recorded, which were confirmed by spectral analysis to be the Central Warning System (CWS) audio tone, though too brief to be easily recognisable as such. There was no apparent crew reaction to these sounds.

Just below 140 kt, the pilot said "…BRAKING", which was followed almost immediately by a further, recognisable CWS audio tone. It lasted about 1.5 seconds: the pilot said (apparently in response to the CWS activation), "OK THAT'S A REV CAPTION GONE TO OVERRIDE". About two seconds later, at 104 kt and with about 575 m (1,890 ft) of runway remaining, the CWS audio tone sounded again, for about 3.6 seconds. As the aircraft approached the runway end, the pilot steered it left by about 20°; it left the paved surface at 33 kt ground speed.

Infra-red (IR) video of the aircraft, recorded by cameras on the AFS vehicles, showed an apparently normal reverse thrust exhaust IR signature from the left hand engine (the right side not being visible); a significant amount of reverse thrust was clearly being achieved on the left engine during the landing roll and at the point the aircraft left the paved surface. However, the images also showed a strong IR plume extending horizontally behind the aircraft from the engine nozzle area. IR images of the rear of the aircraft for some time after the accident showed a significant variation in the IR signature about both engines: the left nozzle area and surrounding structure exhibited more widespread heating than the right side, which showed heating effects confined to the nozzle area only. By about 60 minutes after the accident, IR signatures of both engines were of similar size and shape.

Airport CCTV footage (with frames at one second intervals) also showed an apparent anomaly at the rear of the aircraft which persisted for the entire recorded landing roll. The appearance of the left and right engine nozzle areas was different: what appeared to be reflected sunlight was seen only from the region of the left engine nozzle. As the aircraft left the paved surface, two debris clouds were seen, caused by reverse thrust exhaust efflux; there was a notable difference in size of the two clouds, the left one being larger.

Aircraft information

General

The Tornado GR4A is an armed tactical reconnaissance variant of the Tornado GR4 variable geometry all-weather attack aircraft. The accident aircraft was in a standard squadron configuration, carrying two 1,500 litre external fuel tanks and a range of external stores specific to its role.

Central Warning System (CWS)

The CWS alerts the crew to abnormal and emergency situations, and sytem failures. These are indicated by illumination of amber and red captions on a CWP in each cockpit. Amber captions signify secondary alerts while red captions denote primary warnings and are accompanied by an audio tone. All captions are accompanied by two flashing 'attention getters' on the coaming in each cockpit. Generally, an illuminated caption will cancel automatically when the condition causing it no longer exists. The audio tone and attention getters cancel if the condition no longer exists, or if a crew member pushes either of the attention getters.

Reverse thrust system

Reverse thrust is achieved by swinging buckets into the engine exhaust efflux, deflecting it forwards. The buckets are electrically signalled and pneumatically operated, and each incorporates a mechanism to lock it in the stowed position. Locking is achieved following reverser retraction by linear movement of a dowel into engagement with a lug mounted on the relevant bucket.

Reverse thrust operation is possible only on the ground, when the right main undercarriage 'weight on wheels' switch is made. It is selected by pilot action on the power levers, which sends control signals to the thrust reversers of both engines simultaneously. High pressure engine air is then routed to unlock the reverser buckets, if stowed, and to drive an air motor in either the 'deploy' or 'stow' direction. Three microswitches signal the buckets' positions to the electronic control for safety circuits and cockpit indications.

With the buckets in the reverse thrust position, forward movement of the power levers gives reverse thrust. The power levers can be moved to the maximum dry power position after selection of reverse thrust, irrespective of whether the buckets actually reach the fully deployed position. However, with reverse thrust selected, the reheat range is not selectable.

Reverse thrust system: cockpit indications and controls

Figure 1 shows the main cockpit indications and controls. With the exception of training variants of the Tornado, the control panel is in the front cockpit only. Two three-position magnetic indicators (MIs) show the pilot the status of the reverse thrust buckets. The indicators show grey when the buckets are stowed, cross-hatched when they are in transit, and REV when they are fully deployed. The signals for the MIs come from the microswitches on each engine's reverser mechanism.

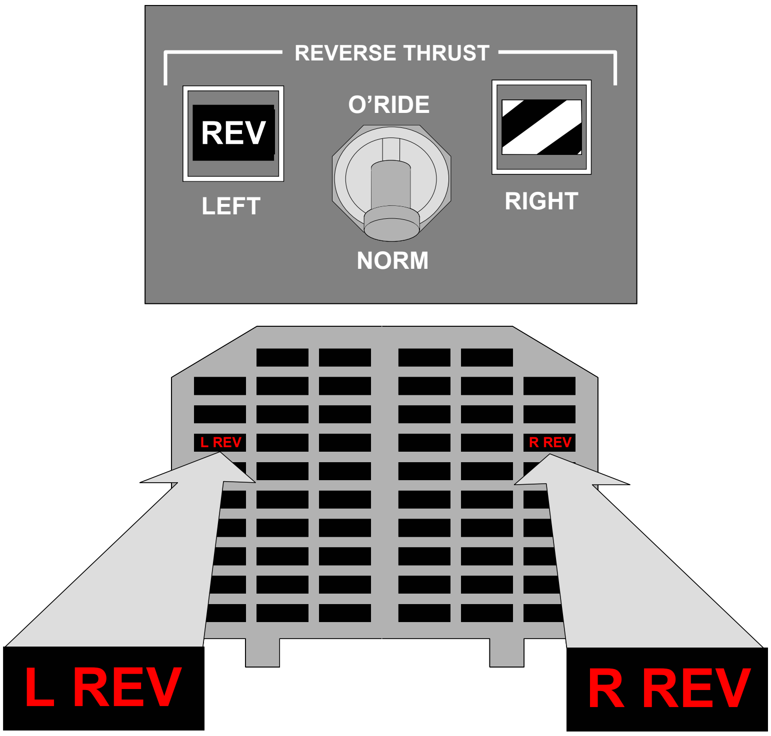

Figure 1

Control panel (top) and CWP (bottom)

Between the MIs is an override switch, used in cases of malfunction and in certain procedures. The CWP includes two red captions, L REV and R REV, which illuminate to indicate thrust reverser malfunction. To avoid confusion in this report, a red CWP caption is hereafter referred to as a CWP REV warning, whilst the MI indication of correct reverse thrust is referred to as an MI REV indication.

Reverse thrust system malfunctions

An inhibit circuit ensures that the reverser buckets of one engine cannot deploy whilst those of the other engine remain in the stowed position. Should an engine's reverser buckets not start to deploy within 0.5 seconds of being commanded, the electrical signals to both engine reversers will be interrupted, causing the buckets to re-stow. Should this occur, the associated CWP REV warning illuminates on the CWP, accompanied by the audio tone. In this case, the warning is 'latched' and can only be cleared by maintenance action. The pilot can still use reverse thrust on the other engine by selecting the system to OVERRIDE; this restores electrical supply to the serviceable reverser, enabling its deployment.

If, having unstowed correctly when commanded, one reverser should fail to reach the fully deployed position, the other reverser will not be inhibited from operating. However, the failed reverser will be indicated to the crew after a two-second delay by illumination of the relevant CWP L REV or R REV warning, together with the audio tone. In this failure case, the CWP REV warning is not latched; it will extinguish (and the audio tone will cease) if the microswitches subsequently sense a fully deployed or stowed condition. As the serviceable reverser system is not inhibited in this case, the override switch has no effect.

The FCC gave crew actions for a CWP REV warning in flight but not during landing. Similarly, the Aircrew Manual for the Tornado GR4/GR4A did not give crew actions for a ground malfunction. It was noted that the system description in the Aircrew Manual could be read in a way that could cause the reader to understand, incorrectly, that anytime a CWP REV warning illuminated, both engines' reverser buckets would re-stow automatically, when in fact this only occurred if one reverser failed to unstow within 0.5 seconds of selection, as described above.

Reverse thrust system testing

A series of tests were carried out using external pneumatic pressure supplies and external electrical power. The left engine reverse thrust system was tested and functioned normally. The right engine reverse thrust system failed to function when tested in its 'as found' condition, but tested normally when the C3 connector was electrically bypassed. The connector, and the servo valve to which it connected, were subjected to detailed examinations; these showed that both were serviceable items.

Further tests, designed to simulate an intermittent connection at the C3 connector, were conducted on a ground training aircraft at a Tornado maintenance training facility. When the reverse thrust system was operated with the simulated intermittent C3 connection present, the reverse buckets on that engine would 'hunt' in various positions. It was found that they could move briefly to the fully deployed position, before retracting again and hunting about the stowed position. On occasions, the reverse buckets 'bounced' into the locked position, initiating movement of the locking dowel. However, the buckets quickly moved out of the locked position again, before the locking dowel could engage. As a result, the tests sometimes ended with the buckets sitting against the locking dowel, in the manner in which the lower right hand bucket of ZA 371 had been found after the accident.

During the tests, a cockpit REV indication showed on the MI when the buckets reached the full deploy position, but would flicker at other times. It was noted that a CWP REV warning, and audio tone, could be generated if the reverser did not reach the fully deployed or stowed positions within two seconds. However, momentary closure of the position sensing microswitches as the buckets hunted often resulted in very brief activation of the warning and tone.

Airport information

Newcastle Airport (elevation 266 ft amsl) has a single runway, designated 07/25, which is 2,329 m long. The threshold of Runway 07 is displaced by 120 m, giving a Landing Distance Available (LDA) of 2,209 m. There is also a 15 m stopway[2] and a 90 m Runway End Safety Area[3] (RESA). The runway and stopway are 46 m wide, with an overall 0.35% down slope. The runway is equipped with lighting appropriate to a major airport, including red runway end lights. By comparison, the main runway at the crew's home base was 2,786 m long with arrester cables at between 488 and 690 m from each end. In common with other military runways, it is equipped with 'distance-to-go' marker boards, placed at each 1,000 ft along the runway: the runway at Newcastle Airport, like most civilian runways, was not so equipped.

The Newcastle runway is grooved along its full length to aid removal of surface water and thereby improve the takeoff and landing performance of aircraft. The runway was inspected hourly by the airport authority for condition and defects: the last inspection before the accident was at 1539 hrs, when the runway was reported to be serviceable.

Landing performance

The Tornado is unusual amongst modern fighter/attack aircraft in that it employs reverse engine thrust to aid stopping performance. It also uses a lift dump system, which deploys spoiler panels on the upper surface of each wing after landing. Reverse thrust is the main stopping aid. Wheel brakes are normally only used towards the end of the landing roll, and not normally above 140 kt. The aircraft is also equipped with a hook which is capable of engaging arrester cables, although cables are not installed at most civilian airfields in the UK.

Following the accident to ZA371, the aircraft manufacturer made a number of performance computations (based upon flight test results and computer modelling), for the aircraft's actual mass and configuration. These showed that, with only one engine at maximum reverse thrust and the other engine remaining at forward idle thrust, the aircraft was capable of stopping well within the LDA at Newcastle if wheel brakes were used from 140 kt. It was also determined that the aircraft could have been stopped within the remaining LDA when the first recognisable CWP REV warning occurred, at about 130 kt, provided that the right engine power lever was retarded to idle at that point and full wheel braking was used.

Footnote

[2] Stopway is an area immediately beyond the end of the declared LDA, capable of supporting the aircraft's weight but not necessarily sharing all the runway's characteristics. At Newcastle, the stopway is a paved surface.

[3] RESA is an area beyond the end of the runway and stopway, intended to reduce the risk of damage to an aircraft undershooting or overrunning the paved surface.

Previous disturbances of the reverse thrust system

The RAF BoI found that, since the right engine (complete with its reverse thrust system), was installed in the aircraft in December 2007, there had been no documented maintenance action which was likely to have disturbed the C3 connector; it was considered unlikely that an unofficial and unrecorded disturbance had taken place.

The last known disturbance of the C3 connector prior to engine installation was following post-rebuild engine runs, carried out on a dedicated engine test-bed. The reverse thrust system was inhibited for these runs, but reinstated prior to installation in the aircraft, and a maintenance requirement raised for functional testing. Existing documentation called for an independent inspection of the thrust reverse system, including the C3 connector, when it was disturbed during this process. However, it was found that this procedure was not routinely followed during the engine run and installation process.

The RAF BoI concluded that the C3 connector had been incorrectly fitted after the engine runs, when the reverse thrust system was reinstated prior to engine installation. No independent inspection of the connector took place and the engine was installed in ZA 371 in this condition.

Analysis

The flight was correctly authorised, and the crew was operating the aircraft within applicable manoeuvring limitations when the bird strike occurred. There was a choice of diversion airfields, but Newcastle Airport was the closest. The decision to divert there was in line with normal operating procedures.

The approach and landing were made at a heavier than normal landing mass (although below maximum), and with a reduced flap setting. These factors produced a final approach speed considerably in excess of the norm. Although the aircraft was capable of landing and stopping on the runway, the LDA was shorter than at the crew's home airfield, and the runway had no arrester cables. Consequently, any malfunction likely to adversely affect the aircraft's landing performance would require prompt recognition and response by the crew. The lack of runway distance-to-go marker boards would compound the situation, as it deprived the crew of critical information normally available to them at military airfields.

Considering the unusual configuration and speed, and consequent reduced safety margins, more detailed and relevant discussion between the pilot and the WSO may have better prepared the crew to deal with a subsequent reverse thrust failure. Although a precautionary single-engine approach profile was flown, the inferred possibility of landing at high speed with only one thrust reverser operative was not voiced in the cockpit. The discussion between the pilot and the crew of the lead Tornado about the damaged FLIR was a distraction at a critical time of the approach and probably contributed to the lack of a pre-landing briefing.

It is probable that the incorrectly fastened C3 connector had been present as a latent fault on the aircraft since the right engine was installed some eight months before the accident. The connector had been held in place by the electrical harness to which it was attached and it was probably the friction of the two contact pins that enabled them to remain engaged. The unfastened state of the connector, however, would have permitted progressive disengagement of the contact pins to occur over a prolonged period. During touchdown on the accident flight, this movement became sufficient for the connection to become intermittent. The reverser buckets probably deployed briefly initially, before oscillating between the stowed and deployed positions. The result of the right reverser bucket movement sequence was that the aircraft spent most of the landing run with full reverse thrust on one engine and a thrust situation varying between full reverse and full forward thrust on the other engine.

The left engine thrust reverser was serviceable and had operated correctly during the landing. The right engine control unit memory had not recorded a buckets 'fully deployed' signal at any stage of the landing roll, indicating that periods at full deployment would have been short (less than half a second). This, with the observed stopping performance and cockpit indications, suggests that the right engine reverse thrust buckets probably moved about a mean position which was closer to fully stowed than fully deployed.

Tests proved that the fault was capable of producing intermittent MI REV indications (as seen by the pilot later in the landing roll), and the sequence of very short CWS audio tones heard on the recordings. It was considered by the RAF Board of Inquiry that the pilot had probably seen the correct reverse thrust indications before advancing the power levers. He next looked at the MIs when it became apparent that the aircraft was not decelerating. Up to this point the lack of a recognisable CWP REV warning would have tended to confirm to the crew that the reverse thrust system was operating normally.

Reverse thrust malfunction indications were reportedly not uncommon during landing, though they were normally the result of minor microswitch rigging errors, causing the timer relays to sense an incorrect operation. This would be most likely to occur within 2 seconds of the pilot selecting (or deselecting) reverse thrust; fault indications part way through the landing roll were far less common. Thus, on most occasions when pilots were faced with CWP REV warnings, the power levers would be at idle. For a reverse thrust malfunction on landing, pilots would expect to have to make a decision about which power lever to *advance*, not about which to retard.

The action of selecting OVERRIDE would allow deployment of a serviceable reverser only if it had been inhibited from deploying through the 0.5 second timer relay. In all other cases (including this accident), selecting OVERRIDE would have no effect, since the serviceable reverser was not inhibited from operation. The logic of the system design was aimed at limiting the possibility of inadvertent thrust asymmetry. Whilst this was effective in the case of a 'hard' failure, it was not designed to cope with a rapidly changing condition between open and closed circuit in part of the operating system.

The pilot selected OVERRIDE when he noticed the MI REV indication flickering, and just before he first noticed the CWP R REV warning illuminate, at about 130 kt. His mindset would initially have been that the power levers were in the correct place for reverse thrust, since he had perceived no contrary indications to that point. When the REV warning then extinguished, it would have served to confirm to the pilot that his action had been successful, although a further check of the MIs would have shown that the right-hand buckets were still cycling. It is probably only when the CWP REV warning illuminated again shortly afterwards, that the pilot realised his action had not corrected the situation. At this point, the remaining stopping distance had reduced to about 600 m and, with the aircraft still at about 100 kt, the pilot recognised that a runway overrun was likely. The overrun situation rapidly became the pilot's priority (crew ejection may be warranted in a serious overrun case), particularly as the WSO was relatively inexperienced. The pilot therefore had minimal time or capacity, from that stage on, to further analyse the reverse thrust indications.

Although the malfunction as presented to the pilot may have been confusing and was certainly not common, the meaning of both a CWP REV warning and the lack of a REV indication on an MI was unambiguous – the reverse thrust buckets for the associated engine were not fully deployed. In either case, the priority should have been to retard the power lever to idle, and if this had occurred in a timely manner in response to either indication, the aircraft would, according to the performance analysis, have stopped on the paved surface.

Recommendations

The RAF BoI made a number of recommendations. These included actions to improve and clarify working practices within the relevant maintenance departments at the aircraft's base airfield, and improvements to Tornado flight crew training and reference documentation.

Conclusion

The latent fault in the right engine's reverse thrust system manifested itself during a precautionary landing which, because of the aircraft's weight and configuration, had to be made at unusually high speed. The nature of the fault was such that it was not clearly indicated to the crew until the aircraft had travelled a considerable distance along the runway, the poor deceleration probably being masked initially by the higher than usual speed. Cockpit indications accurately reflected the fault, but faced with an unusual and poorly documented failure case in a time-critical situation, the pilot did not take the appropriate action of retarding the right power lever.

ACCIDENT

Aircraft Type and Registration:	Dyn'Aero MCR-01, 21-YV (callsign F-JQHZ)
No & Type of Engines:	1 Rotax 912 piston engine
Year of Manufacture:	1997
Date & Time (UTC):	11 April 2008 at 1620 hrs
Location:	Highclere, Hampshire
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - None
Injuries:	Crew - 1 (Serious) Passengers - N/A
Nature of Damage:	Aircraft destroyed
Commander's Licence:	Private Pilot's Licence
Commander's Age:	40 years
Commander's Flying Experience:	950 hours (of which 60 were on type) Last 90 days - 16 hours Last 28 days - 7 hours
Information Source:	AAIB Field Investigation

Synopsis

On approach to a small private landing field, the aircraft rolled left and crashed in the garden of a private house. The loss of control was probably caused by loss of airspeed in gusty conditions as the pilot attempted to approach the confined landing area. The investigation found no indication of any mechanical defect that would have contributed to the accident.

History of the flight

The pilot was returning from Panshangar in Hertfordshire to a field at his wife's home on the edge of Highclere village in Hampshire. Visibility was good with a strong westerly wind, reported locally as gusting up to 28 kt. Departing Panshangar at around midday, he arrived overhead the landing field shortly before 1330 hrs, making one low approach and go-around into a right-hand circuit, in order to inspect the field before landing. On the subsequent approach he encountered a strong crosswind and turbulence and decided to divert to Popham, landing there at 1334 hrs. After shutting down the aircraft he walked to the clubhouse and asked the radio operator to advise him "if the wind drops".

Around one hour later, when advised that the wind speed had decreased to approximately 9 kt, the pilot told the radio operator that he would "have another look at Highclere". He took off at 1442 hrs and made one further approach to the landing field. However, the conditions were such that he decided to return to Popham, where he landed at 1500 hrs. Here, he uplifted 22 ltr of fuel and was seen to leave the aircraft as though having no intention of further flight that day. On returning to the clubhouse he remarked to the radio operator that he had approached the landing field at 40 kt and that the crosswind required him to offset the aircraft heading by 40° in order to maintain the approach track. The pilot remained at Popham until after the clubhouse closed.

Shortly after 1600 hrs, the pilot decided to make one further attempt to land at the field. He recalled that, after an unremarkable takeoff and short flight to Highclere, approximately two minutes before arriving at the landing field and before turning to make another approach, he looked at the cockpit moving map display. He had no recollection of subsequent events.

On this attempt to land at the field, the aircraft departed to the left of the approach path and crashed in a small garden between closely spaced houses. It came to reset inverted and was destroyed, but there was no fire. The pilot, having sustained a severe head injury and broken ribs but no other major fractures, was able to vacate the aircraft with assistance from local residents who had rushed to the scene.

An ambulance arrived shortly afterwards and within 15 minutes had been joined by the Police, Fire and Air Ambulance services. The Fire Service began to inspect the wreckage and found a panel marked with the letters '*BRS*'. When so advised, the AAIB informed them that this denoted the presence of a ballistic recovery parachute system, consisting of a parachute and pyrotechnic rocket launch system. Coincidentally, one of the firemen worked at a nearby airfield and was also aware of the significance of these markings. There was no evidence that the system had been deployed, indicating that the pyrotechnic might still be live, so no further interference was attempted until an AAIB recovery specialist was able to secure its firing mechanism.

Meteorological information

Between 1600 hrs and 1630 hrs, a 'weather station' belonging to the pilot, located at the north end of the strip, recorded a south westerly wind gusting to 25 kt. The pilot reported that the directional element of the system was calibrated to ±10° using a handheld compass, but that it was not calibrated for wind speed. He added that the manufacturer's specification sheet gives the wind speed accuracy as ±3 km/hr and wind direction accuracy as ±7°.

An unofficial wind report for Popham during this period indicated a wind varying in direction from 220° to 270° at speeds up to 28 kt.

Accident site examination

The aircraft had initially struck a large tree bounding the roadside entrance to a detached house on the edge of a small housing estate, just to the left of the aircraft's approach path and almost abeam the threshold end of the intended landing field. It then crashed into the garden of another house beyond the tree, finally coming to rest inverted, against the rear of the building.

The aircraft was destroyed in the impact. The forward fuselage structure was totally disrupted back to a position approximately mid-way between the rudder pedals and the front edge of the seats. The firewall, the forward fuselage deck and integral main fuel tank, which broke open in the impact, and the instrument panel had all separated. Both wings were completely disrupted and had separated from the fuselage; the fin and tailplane were destroyed, but remained attached. There was no fire.

Debris on the ground beneath the tree comprised the whole of the right wing tip fairing, fragmented structure from the tip region of the right wing, the complete tip fairing from the right tailplane, and a number of broken tree branches of up to two inches diameter. The latter corresponded with visible damage to the tree at heights of between 26 ft and 30 ft above ground level, which displayed surface damage and embedded fragments of composite structure consistent with them having been struck by the wing leading edge. More fragments of wing debris were scatted over the ground forward of the tree strike, and the complete tip fairing from the left wing was lodged in the canopy of a smaller tree bounding the garden into which the aircraft finally crashed.

The principal ground impact marks comprised a deep scar made by the aircraft's nose and engine, and a related series of three progressively deepening propeller cuts into the turf of the lawn, of which the final two contained the embedded remains of their respective propeller blades. The character, relative positions, and orientations of these cuts were consistent with the engine having been running at high power at the time of ground impact. The plane of the propeller cuts was orientated approximately 30° to the horizontal, consistent with a fuselage angle having been approximately 30° from the vertical at the time of ground impact. Scrape marks and debris forward of the ground impact showed that the aircraft had subsequently slid along the ground, nosing over towards its left side as it did so causing the top of the canopy to strike the corner of a conservatory attached to the rear of the house. It was apparent that the pilot's head had struck a glancing blow against the brick wall of the conservatory at this location, before the aircraft became inverted fully and was brought to rest against the rear wall of the main building.

Impact trajectory

The distribution of debris and ground marks, together with inferences drawn from a three-dimensional CAD reconstruction of the impact sequence (using suitably scaled representations of the aircraft and principal ground features and objects), suggested that the aircraft was banked slightly left and travelling at significantly high speed, with a slightly upwards trajectory, at the instant it struck the tree. The impact between the right wing tip and the tree caused it to yaw violently to the right and, thereafter, it appears to have followed a slightly lofting trajectory whilst rolling left and pitching nose-down. Just before impact with the ground, the left wing tip struck the small tree bounding the garden into which it finally crashed. This sequence, taken from the CAD reconstruction, is shown in Figure 1.

Detailed wreckage examination

Detailed examination of the wreckage in-situ and subsequently, established that the aircraft was structurally complete and intact at the time it struck the first tree. Both electrically-driven wing flap screw-actuators were at positions which corresponded closely to the 30° setting, and the electric pitch trim mechanism was set approximately 10% on the nose-up side of neutral at the time of ground impact. All the flying controls were intact and connected, and no evidence was found of any malfunction or failure of the airframe or flying controls that could have explained the accident. No detailed examination of the engine was carried out, given the clear evidence of high engine power and airspeed at the time of impact with the house. Neither the propeller governor nor the oil pipes and unions associated with the propeller pitch control system, displayed any evidence of leakage. Sufficient oil remained in the tank to supply the propeller pitch control system. In summary, the

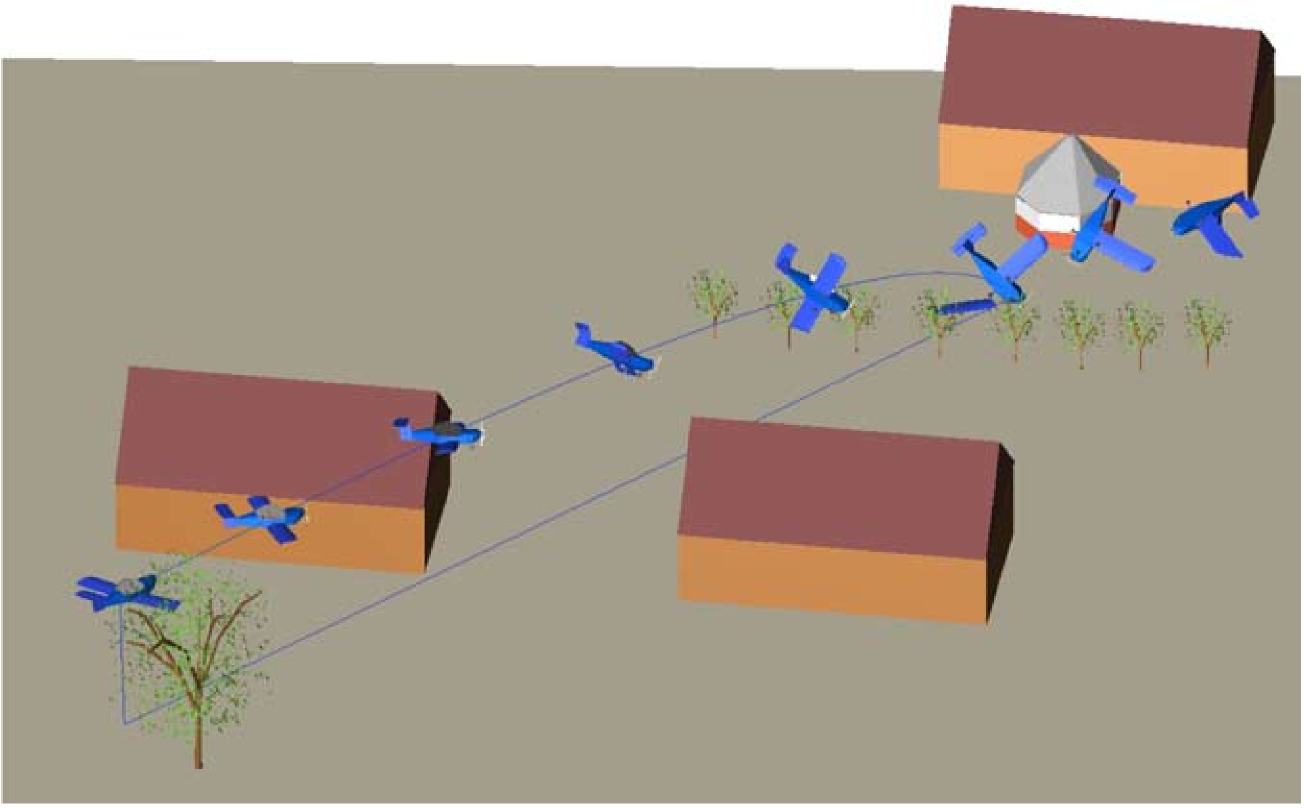

Figure 1
CAD representation of the impact sequence

aircraft appeared to have been fully serviceable at the time of the accident.

Ballistic parachute recovery system

The aircraft was fitted with a BRS Inc aircraft emergency parachute, housed internally in a compartment in the fuselage just behind the canopy and beneath a detachable cover which formed part of the fuselage upper surface. The parachute lines were anchored to the bulkhead structure immediately behind the seats. With this system the parachute is deployed by means of an upwards firing rocket projectile, housed in a container at the rear of the parachute compartment and which, according to the manufacturer's literature, is designed to accelerate to a velocity in excess of 100 mph within a tenth of a second of ignition.

Initiation of the rocket is at the command of the pilot, by means of a firm pull applied to a Tee handle located just beneath the instrument panel. This handle is attached to a bowden type cable connected to a firing mechanism at the base of the rocket motor pack. The system is rigged so that, when the handle is pulled, it first moves through a distance of more than two inches, sufficient for the handle to come completely out of its housing, before any tension is put into the cable; thereafter, a pull force of 30 lbf to 40 lbf is required, through an additional 7/16 inch of cable movement, to initiate the rocket.

Two warning placards were displayed on the exterior of the aircraft; a BRS parachute logo on the parachute compartment cover, Figure 2, and a small red triangle on the fuselage top surface just aft of the parachute compartment, bearing the legend, *'DANGER FUSEE DEXTRACTION PARACHUTE'* (DANGER ROCKET EXTRACTION PARACHUTE), with an arrow pointing towards the parachute compartment, Figure 3. Neither contained any explicit reference to pyrotechnic or projectile hazards. The BRS logo was also displayed on the top surface of the parachute within the compartment, Figure 3.

Figure 2

Parachute compartment cover displaying the BRS placard

Figure 3

Red warning triangle and BRS placard (displayed on the parachute)

Recorded information

The aircraft was equipped with a GPS receiver that recorded the aircraft's track, geometric altitude and ground speed on each of the three sectors flown on the day of the accident. The tracks, timings and ground speeds were consistent with the information provided by the pilot and other witnesses.

Notably, the point at which the final flight appears to have deviated from the approach track at the start of the accident sequence, was close to the point at which the pilot executed a go-around on each of the previous approaches.

Aircraft operations

The pilot's handbook for this aircraft presents tables of stall speed in km/hr for two typical operating weights, are shown in Table 1.

The handbook also indicates that, at a weight of 450 kg, the takeoff ground roll is 150 m and the takeoff distance to clear a 15 m obstacle is 230 m. It indicates a landing distance, on a hard runway in standard atmospheric conditions, of 270 m. The manual states that the normal approach speed is 82 km/h (44 kt).

The pilot stated that he would usually approach the landing field at 45 kt to 50 kt. In doing so, he would compare the airspeed indicator and ground speed information on the GPS receiver in order to judge headwind. He would initially use 30° of flap then, approximately 50 m before crossing the boundary of the field, select 45° of flap if conditions were "not too gusty", but he could not recall what setting he used on the approach on the accident flight. He commented that he chose this aircraft type because of its good takeoff and landing performance, and that he had practised both stalling and going around. The torque effect of the propeller would tend to produce a left roll and he noted that, when stalling, this aircraft would commence an uncommanded left roll.

450 kg

	Flaps position	**0°**	**17°**	**30°**	**45°**
Bank angle					
0°		86	73	67	63
30°		92	78	72	68
60°		122	103	95	90

400 kg

	Flaps position	**0°**	**17°**	**30°**	**45°**
Bank angle					
0°		81	68	64	60
30°		87	73	68	64
60°		115	97	90	84

Table 1

The landing field

The pilot stated that he had completed between 20 and 30 landings at the field near his wife's home. He estimated that the field was approximately 350 m long. In fact, it provided a landing run of approximately 260 m, oriented north-south, but was edged by tall trees and other obstructions which reduced the practical landing distance. The landing ground run was usually between 100 m and 150 m, which he considered allowed "a reasonable safety margin". When approaching from the north, the aircraft would fly close to the built-up area of Highclere, over houses on short final approach and within 100 m of several dwellings.

The pilot had completed drainage and other works in the landing field intending to make it suitable for the operation of his aircraft. There was no requirement for the field to be licensed for aircraft operations, except that operations at the field on more than 28 days each year would constitute a 'change of use' under applicable planning legislation. Several neighbours had noted flying activity at the field and one had recorded all the movements he observed. Although this individual had no record of movements conducted in his absence, the information he provided indicated that flying activity had taken place on fewer than 28 days in the last 12 months.

CAP 428 – *'Safety standards at unlicensed aerodromes'*, published by the CAA, is a guidance document for the operation of unlicensed aerodromes. Its contents are not mandatory but are intended to provide *'sound practice'*, stating in part:

> *'The physical characteristics and operating standards should provide a safe operational environment.'*

In relation to runways it states:

> *'The runway should be of sufficient length… to meet the requirements of the aircraft that will operate from the aerodrome.'*

And:

> *'The runway should, wherever possible, be designed such that trees, power lines, high ground or other obstacles do not obstruct its approach and take-off paths. It is recommended that there are no obstacles greater than 150 feet above the average runway elevation within 2,000 metres of the runway mid-point.'*

In relation to low flying at an unlicensed aerodrome, CAP 428 notes:

> *'Rule 5 of the Rules of the Air, amongst other requirements, prohibits flights below 1000 feet over 'congested' areas except when aircraft are taking off or landing at a licensed or government aerodrome. It is therefore most important that climb out, approach and circuit paths at unlicensed aerodromes do not overfly built-up areas.'*

The Rules of the Air are contained in Civil Aviation Publication (CAP) 393, '*The Air Navigation Order'* (ANO), which has statutory force.

Rule 5 of the ANO states, in part:

> *'If an aircraft is flying in circumstances such that more than one of the low flying prohibitions apply, it shall fly at the greatest height required by any of the applicable prohibitions.'*

And:

> *'(3) The low flying prohibitions are as follows*
>
> *(a) Failure of a power unit*
>
> *An aircraft shall not be flown below such height as would enable it to make an emergency landing without causing danger to persons or property on the surface in the event of a power unit failure.*
>
> *(b) The 500 feet rule*
>
> *Except with the written permission of the CAA, an aircraft shall not be flown closer than 500 feet to any person, vessel, vehicle or structure.*
>
> *The 1,000 feet rule*
>
> *Except with the written permission of the CAA, an aircraft flying over a congested area of a city town or settlement shall not fly below a height of 1,000 feet above the highest fixed obstacle within a horizontal radius of 600 metres of the aircraft.'*

Aircraft approaching the landing field from the north would do so less than 1,000 ft above the highest fixed obstacle within a radius of 600 m of the aircraft. Rule 6 of the ANO states:

> *'The exemptions from the low flying prohibitions are as follows—*
>
> *(a) Landing and taking off*
>
> *(i) Any aircraft shall be exempt from the low flying prohibitions in so far as it is flying in accordance with normal aviation practice for the purpose of—*
>
> *(aa) taking off from, landing at or practising approaches to landing at; or*
>
> *(bb) checking navigational aids or procedures at,*
>
> *a Government or licensed aerodrome.*
>
> *(ii) Any aircraft shall be exempt from the 500 feet rule when landing and taking-off in accordance with normal aviation practice or air-taxiing.'*

Rule 6 (ii) does not exempt aircraft from rule 5 (3) (c).

Ballistic parachute system issues - FAA response

Responding to concerns expressed by regulatory, first responder and industry groups regarding the marking of ballistic parachute systems, the FAA issued Special Airworthiness Information Bulletin (SAIB) CE-09-01 dated 21 October 2008. It contained the following recommendation:

> *'We recommend that all make/model airplanes (so affected) be equipped with the ASTM[1] conforming placards suitable to draw the attention of first responders. ASTM F 2316-06 specifies that the aircraft should be externally marked with one danger placard at the exit point of the rocket/parachute and another warning placard on either side of the aircraft that is visible to those entering or approaching the aircraft.'*

The SAIB provided an example of suitable placards, available from the manufacturer of the system fitted to 21-YV. These placards are not dissimilar to those used to mark ejector seat systems on military aircraft and are shown in Figure 4.

Footnote

1 The American Society for Testing and Materials.

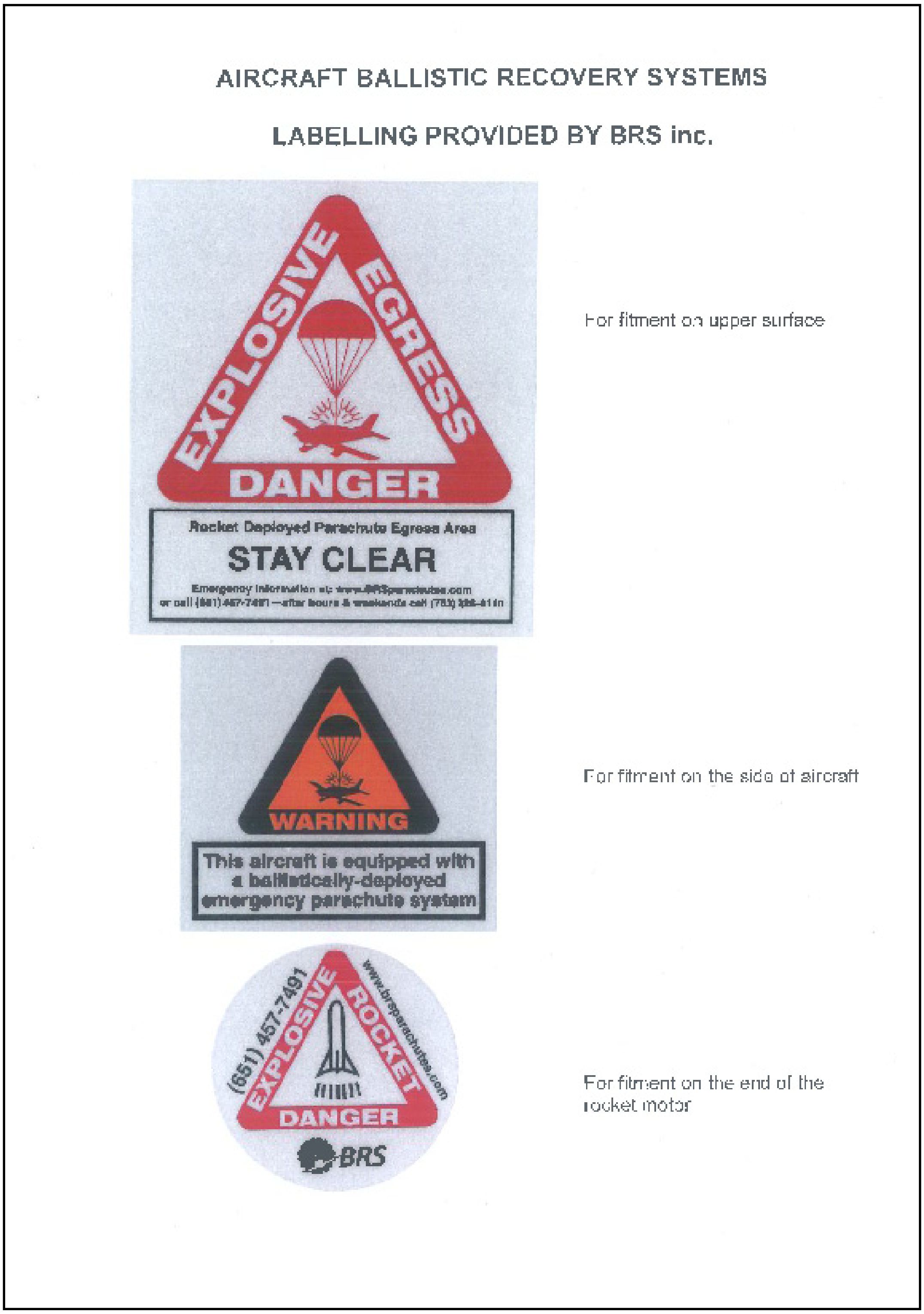

Figure 4

Placards provided by BRS Inc.

Analysis

Aircraft operation

The pilot stated that he had landed at the field on between 20 and 30 occasions prior to the accident which, when approaching from the north, involves flying close to a built-up area, over houses on short final approach and within 100 m of several dwellings. Rule 5 (3) (c) of the Rules of the Air precludes aircraft from operating in to this landing site, due to its proximity to a congested area, and Rule 6 does not exempt them from this rule.

The pilot stated that he usually approached the field at between 45 kt and 50 kt and that he was able to achieve a landing distance less than that indicated by the manufacturer. On this occasion the ground speed recorded by the GPS unit fell to 41 kt in two instances – once when broadly crosswind and again at or about the point where the aircraft deviated from the approach path immediately before the accident. The wind speed and direction recorded at that time would suggest an airspeed of greater than 50 kt at that moment, but the gusty conditions make an accurate assessment of airspeed impossible. It is possible, therefore, that the gusting wind conditions resulted in a temporary reduction in air speed to below that at which the aircraft would stall. Also, the GPS record of ground tracks indicated that the position at which the aircraft appeared to deviate from the approach track was close to the position at which the pilot had executed go-around manoeuvres on each of the previous approaches. It is therefore possible that he had initiated a go-around at this point on the approach of the accident flight.

Either as a result of the stall itself, or the application of power close to the stall during a go-around, the aircraft commenced a roll to the left from which the pilot may have been in the process of recovering when the aircraft hit a tree. It then became uncontrollable and crashed.

BRS issues

The use of a bowden-type cable, and its routing between the Tee handle on the instrument panel and the firing mechanism in the aft fuselage, makes the mechanism inherently vulnerable to disturbance during an accident, with the risk that the rocket may be inadvertently fired, assuming that the pilot has not initiated the system before impact. This is particularly so if structural disruption during the impact stretches or pulls the cable sufficiently to take out the free length rigged into the inner cable, ie putting the cable into tension, which would then require very little additional movement of the cable to initiate the rocket. In such circumstances, any further slight disturbance of the associated structure, or of the cable itself, by first responders attending the scene, for example, whilst attempting to gain access to the aircraft's occupants, could fire the rocket, potentially causing serious injury or even the death, to anyone nearby.

The parachute system fitted to 21-YV, and similar emergency parachute systems that are fitted in increasingly large numbers both to microlight and conventional light aircraft, represents a significant hazard to any one attending the scene of an accident to such aircraft. It follows that there exists a clear and obvious need for people attending such an accident to be made immediately aware that such a system is fitted and also of its implications for their safety. They also need to know the location of the device and the likely trajectory of the rocket (or, in some systems a ballistic) projectile is likely to take in the event of it being inadvertently triggered.

This issue affects not just emergency services personnel, for whom awareness training is both desirable and feasible, but also members of the public who are likely to make the initial efforts to assist the occupants, and who could not be expected to have any prior knowledge of the potential danger. For the latter, there is a clear requirement for highly visible warnings to be placed on the aircraft, at positions where they are likely to be seen, regardless of the aircraft's orientation on the ground, capable of indicating to a lay-person both the nature of the hazard, the location and likely direction of discharge of any associated projectiles. Currently, there are no formal requirements concerning information placed on aircraft fitted with such devices. 21-YV displayed only a BRS parachute logo on the parachute compartment cover and on the top surface of the parachute within, neither of which contained any explicit reference to pyrotechnic or projectile hazards. The red triangle on the fuselage top surface, just aft of the parachute compartment, which bore the legend, *'DANGER FUSEE DEXTRACTION PARACHUTE* (DANGER ROCKET EXTRACTION PARACHUTE)*'*, was small and not considered to be visually compelling.

In the absence of clear information to warn them of its presence, neither the civilian first responders nor any of the emergency personnel were aware of the possibility that the aircraft might contain hazardous pyrotechnics. Furthermore, when interviewed subsequently, none of these personnel were aware of standing guidance about BRS provided to their respective organisations. Also, when interviewed about the accident, personnel at Popham demonstrated little awareness of ballistic parachute systems.

Ballistic parachute systems are already fitted to approximately 300 different types of aircraft around the world, including General Aviation aircraft such as the Cirrus, Cessna 172 and 182, as well as many microlight aircraft. One manufacturer has reportedly sold approximately 28,000 units and stated that around 200 lives have been saved so far. Military aircraft which contain pyrotechnic devices, such as ejection seats, canopy detonating chord and stores jettison systems, have standard, easily recognisable decals applied to the airframe close to these potentially dangerous systems. Historically, as civil aircraft have contained few if any pyrotechnic devices, there has been no need to develop standard placards for informing rescue personnel of their presence following an accident. Aircraft manufacturers and, in this case BRS Inc., apply their own warning decals to aircraft, but these differ between aircraft, and do not conform to any internationally agreed standard. The BRS manufacturer has stated that they have had difficulty in establishing an agreed warning labelling system.

Various documents, such as BCAR Section S (Sub-section K), ICAO State Letter No AN6/26-05/46, and BMAA TIL No 16, contain information relating to warnings that should be applied to aircraft fitted with a ballistic recovery system, but the format of such warnings is not specified. It is, however, a CAA requirement that a warning placard relating to an installation must be visible on the outside of a microlight aircraft close to the *'stored energy device'*. The small red decal on 21-YV was not readily visible to rescue personnel due to the attitude of the fuselage, and was not considered to be visually compelling.

As the number of aircraft fitted with a ballistic recovery system is likely to increase, first responders, who are likely to be members of the public, to an accident involving such aircraft are likely to be exposed to an increased risk of injury where these devices remain live within the wreckage.

In 2005, The Australian Transport Safety Board made a Safety Recommendation to ICAO concerning the application of warning placards on aircraft fitted with a ballistic parachute system.

In response to that recommendation, ICAO have stated, in part, the following:

> *'Due consideration to the recommendation was given, including relevant discussions by the ICAO Airworthiness Panel and the issuance of a State Letter. Below is a summary of the actions undertaken by ICAO in that regard:*
>
> *a) States advised of the potential dangers of rocket-deployed emergency parachute systems (ballistic parachute) installed in aircraft are invited to review the adequacy of the warning placards required for such devices and to ensure that emergency responders, such as police, ambulance, rescue/fire service and accident investigators as well as maintenance personnel, are aware of the potential hazards posed by such devices and of the correct means to render such devices safe (State letter AN6/26-05/46, dated 12 August 2005 refers);*
>
> *b) Incorporation into the Manual of Aircraft Accident and Incident Investigation (Doc 9756) and in Circular 315, Hazards at Accident Sites, of reference material addressing the potential hazards of such devices, as well as guidance on appropriate safety precautions; and*
>
> *c) Consideration by the Airworthiness panel of an amendment to Annex 8 - Airworthiness of Aircraft - requiring warning placards in aircraft fitted with ballistic parachute systems, in order to draw attention to potential associated hazards. During its deliberations, the Panel concluded that requiring such warning placards would not increase safety at accident sites. Warning placards might not be visible in some conditions such as during low visibility and it was also agreed that personnel close enough to read the placards would already be inside the danger zone of the equipment.'*

However, this response is not considered to address the real possibility that a first responder is highly likely to be a member of the public, with no knowledge of the potential danger that such systems pose in the event of an accident. In order to minimise the risk, the following Safety Recommendation is made:

Safety Recommendation 2009-007

It is recommended that the International Civil Aviation Organisation publish a Standard which defines internationally agreed warning placards for application to all aircraft fitted with ballistic parachute recovery systems, that give as clear an indication as possible at the greatest distance reasonable of the dangers posed to first responders to an accident aircraft fitted with a ballistic parachute recovery system.

Whilst providing a model that might address these issues, the SAIB issued by the FAA is not an airworthiness directive and, consequently, is not mandatory. Accordingly, the following Safety Recommendation is made.

Safety Recommendation 2009-008

It is recommended that the Federal Aviation Administration, the Civil Aviation Authority and European Aviation Safety Agency, cooperate to require the application of warning placards of a common agreed standard, to be applied to all aircraft fitted with ballistic parachute recovery systems for which they have airworthiness responsibility, to maximise the possibility of first responders being made aware of the danger posed by a live system following an accident. These placards should be applied in such a manner that at least one such placard should remain visible regardless of the stationary attitude of the aircraft.

ACCIDENT

Aircraft Type and Registration:	DA 42 Twin Star, G-SUEA
No & Type of Engines:	2 Thielert TAE 125-02-99 piston engines
Year of Manufacture:	2007
Date & Time (UTC):	20 January 2009 at 1457 hrs
Location:	Lands End Aerodrome, Cornwall
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - 2
Injuries:	Crew - 1 (Minor) Passengers - 2 (Minor)
Nature of Damage:	Substantial damage to forward fueslage and propellers
Commander's Licence:	Private Pilot's Licence
Commander's Age:	47 years
Commander's Flying Experience:	1,315 hours (of which 62 were on type) Last 90 days - 38 hours Last 28 days - 10 hours
Information Source:	AAIB Field Investigation

Synopsis

The aircraft overturned on soft ground beyond the airfield boundary following a rejected takeoff. The takeoff distance available was less than that required by the aircraft under the prevailing conditions to become safely airborne.

History of the flight

Prior to departure from Stapleford, the pilot telephoned the ATC tower at Lands End and was advised against attempting the trip due to poor weather. However, the pilot took off and was able to avoid the bad weather using the aircraft's weather mapping system. By the time G-SUEA arrived at Lands End the storms had passed and the weather had improved. The aircraft landed on Runway 25. The pilot noted that the airfield's grass surface was very wet, particularly around the hard standing areas beneath the ATC tower where he was instructed to park.

When the pilot returned to the aircraft, he carried out his normal pre-flight checks. He noted that the left engine oil quantity was low and added approximately one quart of oil. He reported that the engines started without difficulty and carried out the normal power checks, without problems.

When the pilot began to taxi onto the grass area from the hardstanding, the aircraft became bogged down in the soft ground. He shut down the engines and an Airport Fire Services (AFS) vehicle towed the aircraft back onto the area of hardstanding. They also washed the landing gear which had become contaminated with mud during the pilot's initial attempts to extricate the aircraft from the soft ground with the use of full power.

Having by now performed several engine starts, the pilot was aware of a L ECU A FAIL caption illuminating on the Primary Flight Display, indicating a failure in the left engine control system. He reported that the warning was not always present on engine start-up and he therefore decided to continue with his preparations for the flight.

The pilot then taxied the aircraft across the airfield to line up on Runway 25. From the wheel tracks on the runway, the position of the aircraft at the start of this takeoff roll would have given a runway distance remaining of 465 m. As engine power was increased to begin the takeoff roll, the aircraft immediately became bogged down again, so the pilot shut down the engines.

The AFS then towed the aircraft to the right side of Runway 25, adjacent to the normal threshold, Figure 1. The pilot reported that he thought his location was closer to the airport buildings and on the left side of Runway 25. He then attempted to take off. His plan was to track alongside Runway 25, displaced to the left, which he felt was firmer ground than on the runway itself. As power was increased, the aircraft accelerated. The pilot was closely monitoring the airspeed, hoping to reach 70 kt in order to be able to lift off. However, at around 46 kt he reported a "pull to the left" and became aware of the L ECU A FAIL caption being illuminated. He then retarded the throttles and aborted the takeoff.

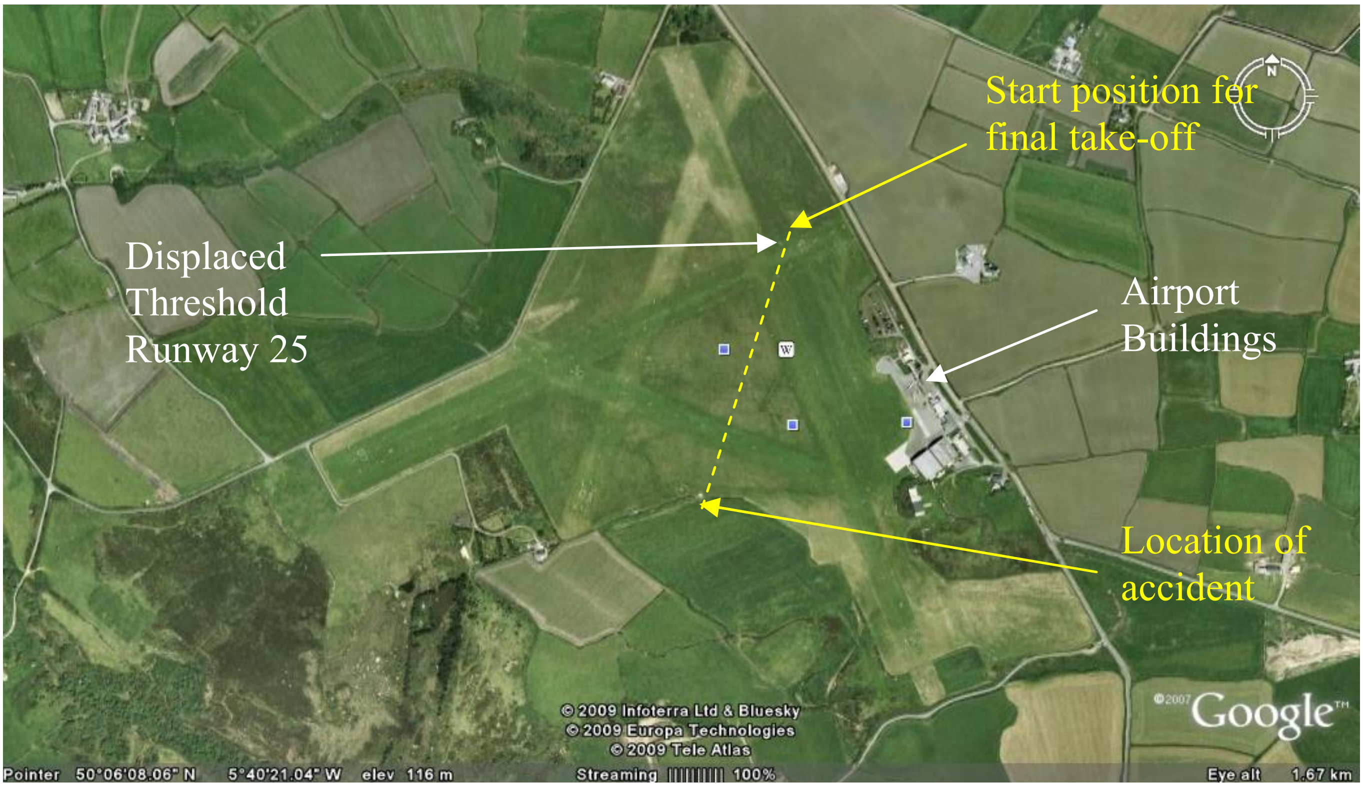

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Figure 1

Lands End Airfield

The wheel marks on the airfield indicated that the aircraft had followed a straight track in a direction of approximately 200° from its start location on the right side of Runway 25. It had covered approximately 350 m when it crossed the airfield boundary and entered a ploughed field. The aircraft immediately nosed over in the very soft ground, coming to rest inverted.

The AFS attended and the pilot and both passengers, who all suffered minor injuries, were assisted in escaping from the aircraft. There was no fire.

A special meteorological observation taken just after the accident gave the surface wind as 250/14 kt, unlimited visibility, clouds FEW012 and FEW016CB, with a temperature of +5ºC.

Engine description

The DA 42 is fitted with two Thielert TAE 125-02-99 liquid-cooled, four-cylinder, four-stroke, turbocharged common-rail direct injection diesel engines, designed to run on Jet A-1 fuel. Each engine is rated (takeoff power) at 99 kW (135 DIN HP) at 2,300 rpm at sea level ISA conditions, and drives a three-bladed, variable-pitch, wood-composite propeller via a 1:1.69 reduction gearbox. The maximum allowable continuous propeller speed is 2,300 rpm, corresponding to an engine speed of 3,900 rpm. The engine and propeller are controlled by a dual channel, digital Engine Control Unit (ECU).

The ECU electronically controls the manifold pressure, fuel rail pressure (which determines the quantity of fuel injected) and propeller speed, according to the power lever position. The engine is normally controlled and regulated by Channel A. However, if a failure is detected, Channel B will automatically take over control. Also, the ECU records fault information in an 'event log' and time history information at one second intervals for various engine parameters.

Engine parameters, including propeller speed and engine load (as a percentage derived from the manifold pressure) are displayed on a central Multi Function Display (MFD) in the cockpit. The Primary Flight Display (PFD) displays the crew alerting (annunciator) system, in addition to air data, attitude, and heading information. A warning or caution annunciator will flash on the PFD, accompanied by an aural tone. A warning is accompanied by a repeating tone and a caution is accompanied by a single tone.

In case of minor faults, the annunciation can be reset once by pressing the ECU TEST button for more than 2 seconds. However, the annunciation will re-appear upon the next attempt to start the engine.

Engine examination

A download was performed to extract the fault information and time history data from both ECUs. The data was supplied to the engine manufacturer for assistance in interpreting the information.

There were no faults recorded by the right engine ECU. The data from the left ECU indicated that the engine was shut down at 1119 hrs with Channel A active and no faults recorded. The first warnings were recorded at around 1202 hrs when oil temperature (TOIL), coolant temperature (TH2O), outside air temperature (TAIR), oil pressure (POIL), fuel rail pressure (PRAIL) and gearbox temperature (TGEAR) sensor failures were detected. These sensor faults would have resulted in a flashing L ECU A caution. The engine was started at 1357 hrs and since the 'health' of Channel A was lower than that of Channel B, control of the engine automatically passed to Channel B.

AT 1358 hrs the engine was re-started with Channel B in control. The ECU test button was reset, which should have resulted in the flashing L ECU A FAIL caution becoming steady. There were various resets and engine restarts, all of which would have resulted in a steady L ECU A caution.

At 1450 hrs the final takeoff attempt began with left engine ECU Channel B in control; a steady L ECU A caution would have been illuminated.

The data shows an increase of engine power on both engines to maximum for 28 seconds, before the power decreased and both engine speeds reduce to zero. Both ECUs continued to record information until the battery became depleted.

Flight Manual Abnormal Operating Procedures

The Flight Manual Abnormal Operating Procedures following an ECU fail caption states:

> ***'L/R ECU A FAIL***
>
> *(a) 'ECU A' caution on ground*
>
> - *Terminate flight preparation*
>
> *(b) 'ECU A' caution during flight*
>
> ***NOTE***
>
> *In case of a failure on the electronic ECU (Engine Control Unit) 'A' the system automatically switches to ECU 'B'*
>
> *1. Press the ECU TEST button for more than 2 seconds to reset the caution message*
>
> *if ECU A caution message reappears, or cannot be reset;*
>
> *2. Land on the nearest suitable airfield.*
>
> *3. The Engine must be serviced after landing*
>
> *if ECU A caution message can be reset;*
>
> *2. Continue flight.*
>
> *3. The Engine must be serviced after landing'*

Airfield information

There are four grass runways at Lands End Airfield; Runway 25 has a declared Take Off Run Available (TORA) of 695 m and this allows for a displaced threshold due to the proximity of vehicles on an adjacent road. It slopes downhill by 32 m along its length, giving a gradient of 4.6%. The UK AIP states that:

> *'both Runways 16/34 and 07/25 are sufficiently wide to allow differential use of each side of the runway in order to conserve the grass surfaces.'*

The UK AIP also states:

> *'some parts of the manoeuvring areas are undulating.'*

A NOTAM was issued from Lands End at 1000 hrs UTC on the day of the accident which further displaced the threshold of Runway 25 due to soft ground; the TORA was reduced to 574 m.

The ground actually traversed by G-SUEA was from the threshold of Runway 25 to its final position beyond the airfield boundary, between the thresholds of Runways 02 and 34. The elevation at the accident location was approximately 384 m, giving a very slight downslope from the threshold elevation of 389 m of Runway 25.

Aircraft performance

The Aircraft Flight Manual (AFM) contains aircraft performance information and also states:

> ***'WARNING***
>
> *For a safe takeoff the available runway length must be at least equal to the takeoff distance over a 50 ft (15m) obstacle.*
>
> ***CAUTION***
>
> *The figures in the following NOTE are typical values. On wet ground or wet soft grass covered runways the takeoff roll may become significantly longer than stated below. In any case the pilot must allow for the condition of the runway to ensure a safe takeoff.*
>
> ***NOTE***
>
> *For takeoff from dry, short-cut grass covered runways, the following corrections must be taken into account, compare to paved runways (typical values, see CAUTION above)*
>
> - *grass up to 5cm (2 in) long: 10% increase in takeoff roll*
> - *grass 5-10cm (2 to 4 in) long: 15% increase in takeoff roll*
> - *grass longer than 10cm (4 in): 25% increase in takeoff roll*
> - *on grass longer than 25cm (10 in): takeoff should not be attempted.'*

The data supplied in the Aircraft Flight Manual (AFM) is unfactored. CAA Safety Sense Leaflet (SSL)7c, '*Aeroplane Performance'*, states:

> *'It is strongly recommended that the appropriate Public Transport factor, or one corresponding to that requirement, should be applied for all flights. For take-off this factor is x 1.33 and applies to all single-engined aeroplanes and to multi-engined aeroplanes with limited performance scheduling (Group E). This factor allows for lack of practice, incorrect speeds/techniques, aeroplane and engine wear and tear, and less than favourable conditions.'*

The leaflet also details further factors which should be applied in certain circumstances. For example, on firm dry grass runways an increase of 20% should be applied to the takeoff distance and, on soft ground, this rises to 25%. These factors are cumulative and the overall factor of 1.33 should then be applied. Given the weight of the aircraft and its occupants, temperature conditions and approximate fuel load of ⅔ of the maximum, the takeoff distance indicated by the AFM is 490 m. This increases to 588 m when taking off from a firm dry grass surface, 735 m from soft ground, rising to 977 m when the overall 1.33 factor is applied.

SSL7c also warns:

> *'grass, soft ground or snow increase rolling resistance and therefore the take-off ground run. When the ground is soft, a heavy aircraft may 'dig in' and never reach take-off speed.'*

Analysis

Having experienced a number of left engine ECU A fault indications during start-up, the AFM advises that an operator should *'Terminate flight preparation'*. Therefore, it would have been advisable for the pilot to have sought assistance before continuing with his preparations for flight.

The multiple sensor failure indications were associated with sensors which supply information to both channels of the left ECU. However, only Channel A recorded failures, and these were intermittent. It is therefore unlikely that these failures logged by the ECU were due to faults with the sensors or their wiring.

Despite the left engine ECU A warning, the recorded information indicated that both engines developed full power during the last attempted takeoff. The distance travelled from the aircraft's start position, beside Runway 25, to the accident location, was around 350 m and this was insufficient distance for the aircraft to have become airborne.

The pilot's decision to continue with the takeoff, off runway and despite the outcome of the first attempt, was ill-advised. CAA Safety Sense Leaflet 23 – *'Pilot's its Your Decision'* discusses issues surrounding the decision making process with regard to flying. In his report, the pilot stated that it was the wrong decision to attempt a takeoff at all and concluded that he would not be operating a DA-42 from a wet grass surface again.

ACCIDENT

Aircraft Type and Registration:	Diamond DA42 Twin Star, G-CTCF
No & Type of Engines:	2 Thielert TAE 125-02-99 piston engines
Year of Manufacture:	2005
Date & Time (UTC):	30 May 2008 at 1700 hrs
Location:	Bournemouth International Airport, Dorset
Type of Flight:	Training
Persons on Board:	Crew - 2 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	Nosewheel retaining bolt detached from bracket
Commander's Licence:	Commercial Pilot's Licence
Commander's Age:	41 years
Commander's Flying Experience:	2,599 hours (of which 705 were on type) Last 90 days - 29 hours Last 28 days - 9 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

Synopsis

As the aircraft came to a stop at its parking position after landing, the landing gear unsafe warning illuminated. Inspection of the nose landing gear revealed that a nose gear strut retaining bolt had separated from a bracket on the nose gear bay side wall, allowing the strut to rest against the wall and damage wiring associated with the nose gear warning.

The landing was not considered heavy, but the subsequent de-rotation to nose gear touchdown was described as firm. Maintenance personnel considered that the sidewall could have flexed at nose gear touchdown, allowing the retaining bolt to be dragged from its bracket when nose wheel steering was used at full deflection for parking.

ACCIDENT

Aircraft Type and Registration:	1) Piper PA-28-180 Cherokee, G-AVRK 2) Piper PA-28R-201 Cherokee Arrow III, G-TOLL
No & Type of Engines:	1) 1 Lycoming O-360-A4A piston engine 2) 1 Lycoming IO-360-C1C6 piston engine
Year of Manufacture:	1) 1967 2) 1977
Date & Time (UTC):	14 November 2008 at 1812 hrs
Location:	Coventry Airport
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - 1
Injuries:	Crew - None Passengers - None
Nature of Damage:	Propeller and spinner damaged on both aircraft
Commander's Licence:	Private Pilot's Licence
Commander's Age:	61 years
Commander's Flying Experience:	429 hours (of which 143 were on type) Last 90 days - 5 hours Last 28 days - 2 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

Synopsis

The pilot, who was accompanied by an experienced flying group member, was practising night flying after renewing her night rating two days beforehand . Prior to shutdown after an uneventful flight, the aircraft was positioned to allow a manual push back into a parking slot; the aircraft was about 4 feet from a parked Piper PA-28R, G-TOLL, with the two aircraft approximately nose on to each other. The pilot thought she had set the parking brake and was covering the toe brakes during the shutdown checks. However, with both occupants' attention inside the cockpit, G-AVRK rolled forward towards the other aircraft. There were no sensations or cues of movement and the pilot realised too late what was happening. Although she reapplied the parking brake and shutdown the engine, her aircraft struck the parked aircraft, causing spinner and propeller damage to both. The pilot thought that she may have inadvertently released toe brake pressure as she leant over in the cockpit to read the tachometer.

ACCIDENT

Aircraft Type and Registration:	Piper PA-28R-200 Cherokee Arrow II, G-BKFZ
No & Type of Engines:	1 Lycoming IO-360-C1C piston engine
Year of Manufacture:	1976
Date & Time (UTC):	13 February 2008 at 1535 hrs
Location:	North-eastern edge of Rutland Water, near Empingham, Leicestershire
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - None
Injuries:	Crew - 1 (Fatal) Passengers - N/A
Nature of Damage:	Aircraft destroyed
Commander's Licence:	Private Pilot's Licence
Commander's Age:	85 years
Commander's Flying Experience:	972 hours (of which 850 were on type) Last 90 days - 2 hours Last 28 days - 0 hours
Information Source:	AAIB Field Investigation

Synopsis

The aircraft had departed from Spanhoe Airfield to return to its home base, Shacklewell Lodge, 6 nm to the north-east of Spanhoe. The sky was clear after takeoff but there was an area of very low cloud with mist and fog moving in from the east. The aircraft climbed to 1,200 ft above a cloud layer and the pilot contacted RAF Cottesmore to request their cloudbase. The Cottesmore controller reported that the last observation was 'sky clear' with a visibility of 5,000 m in haze. The pilot acknowledged this information but made no further transmissions.

The aircraft crashed in a park on the north-eastern edge of Rutland Water, where it had struck a pair of trees at a speed in excess of 110 kt, whilst in an approximate 20° bank to the left. Witnesses to the accident described the weather at the time as foggy. The reason for the aircraft's descent into foggy conditions could not be clearly established.

History of the flight

Following maintenance at Spanhoe Airfield, the pilot intended to fly the aircraft back to its base at Shacklewell Lodge, just to the east of Rutland Water. He and his wife were aware of fog in the wider area, so he telephoned the engineer at Spanhoe, who told him that the weather there was clear. The pilot and his wife set off by car from their home, some six miles north-east of Shacklewell, to check the weather at the airfield, before continuing to Spanhoe. The pilot's wife was then to drive the car from Spanhoe to Shacklewell to collect her husband after the flight.

After arriving at Spanhoe, the pilot, in discussion with others there spoke about the possibility of poor weather. Consequently, he informed his wife that if he could not land at Shacklewell, he would return to Spanhoe. The pilot fitted his portable Global Positioning System (GPS) receiver to the aircraft, completed his pre-flight checks and prepared for departure, whilst his wife cleaned the aircraft's windscreen. At about 1515 hrs, he boarded the aircraft, started the engine, and taxied for departure.

The aircraft took off from Runway 27 at 1527 hrs, and made a right turn towards the eastern end of Rutland Water.

At about 1529 hrs, the pilot contacted the approach controller at RAF Cottesmore, stating that he was at 1,200 ft, just above a cloud layer; he requested clearance through the Military Aerodrome Traffic Zone (MATZ) at RAF Wittering. The controller informed the pilot that he was receiving a Flight Information Service, that he was cleared through the Wittering MATZ and that he should report on final approach at Shacklewell. A few moments later, the pilot requested the QFE at Wittering. The controller informed the pilot that Wittering was closed, and that the Cottesmore QFE was 1,019 mb[1]. The pilot then asked the controller for the cloud base at Cottesmore, and the controller replied "REPORTED AT ER FIFTEEN HUNDRED WE'VE GOT VISIBILITY OF FIVE THOUSAND METRES IN HAZE CLOUD ER CLEAR SKY CLEAR". The pilot acknowledged this information.

A few moments later, the controller requested the pilot to confirm that he was now on the ground at Shacklewell, but received no reply. Despite repeated attempts by the controller to contact the aircraft, no further transmissions were received. Very soon afterwards, a Police helicopter pilot contacted the controller, stating that he was en-route to a possible aircraft crash at Rutland Water. Almost immediately afterwards, an air ambulance helicopter pilot also contacted the controller with similar information. The controller then suspected that G-BKFZ had crashed.

Although both helicopter pilots made attempts to reach the accident site, by descending at the edge of the fog bank which covered the area, neither was able to penetrate the thick fog.

Witness information

A number of people were walking in the area of Rutland Water at the time of the accident. They described that the earlier clear and sunny weather had been replaced, suddenly, by very foggy conditions[2].

One witness recalled hearing the sound of a light aircraft, stating that it "sounded like the noise a plane would make if it was diving… there were no breaks in the noise, it was constant". Another stated that "one moment the engine noise was fine and then it faltered and then it was fine again as if it was cutting out and starting up again". Other witnesses gave varying accounts of normal engine noise, or engine noise which they believed was indicative of an aircraft in difficulties. Soon after they first heard the aircraft, some witnesses close to the accident site saw an aircraft emerge from the fog, flying low in a shallow descent, collide with trees and break up.

Footnote

1 RAF Cottesmore is approximately 5 nm NNW of Shacklewell Lodge.

2 See 'Meteorological Information'.

The pilot sustained fatal injuries in the impact.

Information concerning the flight from takeoff until witnesses heard and saw the subsequent accident at Rutland Water, consisted of the RTF recordings from RAF Cottesmore and data downloaded from the pilot's GPS receiver.

Pilot's history

The pilot obtained a Private Pilot's Licence (PPL) with a Single-Engine Piston (SEP) rating in 1984, to which he added an Instrument Meteorological Conditions (IMC) rating in 1988. He last revalidated his IMC rating in December 1994, which expired in January 1997, and completed a 'Biennial Test' in October 2007 to revalidate his SEP rating. His log book showed a total of 68 hrs instrument flight, the last such flight being logged in August 2004.

The pilot had been a co-owner of G-BKFZ for many years and flew regularly, touring in Great Britain and Europe. Throughout this time, the aircraft was based at Shacklewell Lodge and the pilot knew the area and its topography well.

Aircraft information

G-BKFZ was a Piper PA-28R-200, Figure 1, an all-metal low-wing aircraft, powered by a Lycoming IO-360-C1C piston engine driving a three-bladed variable-pitch Hartzell propeller. It was of conventional design with mechanical flying controls, retractable tricycle landing gear and with a wingspan of 9.81 m. At the time of the accident, G-BKFZ had accumulated 3,110 hours flying time, with the engine and propeller 977 hours and 1.5 hours respectively.

The PA-28R-200 consumes, on average, about 9 to 10 US-gallons per hour in normal low altitude cruising flight. The pilot's operating handbook (POH) specifies that the speed to be flown, following engine failure, is 100 mph (87 kt).

Fuel

Before its departure, the maintenance engineer at Spanhoe, who had carried out the work on the aircraft, assessed that both tanks were approximately ¼ full, giving a total fuel on board of about 10 USG. This total amount accorded with various records, taking into account fuel that was taken from the aircraft by the engineer for a variety of cleaning tasks during its maintenance. The distribution of fuel between the left and right tanks, however, could not be confirmed from the records.

Meteorology

An aftercast provided by the Met Office stated:

> *'In summary, the accident appears to have occurred on the boundary between clear skies with haze/mist to the west; and very poor low cloud conditions with mist, fog and hill fog to*

Figure 1

PA-28R-200, G-BKFZ, with a two-bladed propeller fitted *the east', and that 'Visibility associated with the low cloud is reported as being in the range 100 M to 2500 M. Visibility associated with cloud free conditions is likely to have ranged from 2500 M to 8 KM'.*

The temperature on the ground was around 7°C, 8°C at 2,000 ft, and there was colder air around 1,000 ft where the temperature was 4°C. As these temperatures were all positive, airframe icing was unlikely to have affected the aircraft. The mean sea level pressure in the region at the time of the accident was 1036 mb. The wind at 500 ft was estimated at 060°/11 kt.

The police helicopter pilot gave an account of the conditions he met while attempting to reach the accident site. He stated that "approaching the Manton area[3]… conditions were clear" but that when he flew directly over the accident site, the ground could not be seen. He flew back to the edge of the fog and descended, intending to continue the flight in visual contact with the ground. However, the visibility in the fog was so poor that this was not possible. He commented that the top of the fog was between 500 ft and 700 ft above ground level, and that the fog bank was spreading slowly south-west all the time. The air ambulance helicopter pilot gave a very similar account of his flight and the conditions he encountered, noting too that near the accident site "the fog was completely on the ground with visibility less than 100 metres".

The Met Office provided a high resolution visible cloud satellite image taken at 1530 hrs on the day of the accident, Figure 2. It clearly showed the area of fog across eastern England and the North Sea. The accident site, marked with a red X was between RAF Cottesmore and RAF Wittering.

A hot air balloon passed to the south of Rutland Water about half an hour before the accident. The pilot took a picture of the water which showed, at that time, the accident site was covered by an area of low cloud or fog, but with the boundary between the fog and clearer conditions a short distance to the west.

A private pilot, who lived just north-west of Shacklewell, was at home listening to RTF transmissions using an air-band radio. He later recalled that, shortly after 1500 hrs, the weather changed dramatically, with clear and sunny weather giving way within 15 to 20 min, to dense fog, with a visibility estimated at between 150 m and 200 m. Other witnesses in the area also described the conditions changing from clear with bright sunshine, to dense fog.

Recorded information

The hand-held GPS receiver fitted to the aircraft by the pilot before the flight, was powered throughout the flight and had recorded time, position, groundspeed, heading and GPS altitude, every 30 seconds. This device suffered minor damage during the accident but was successfully downloaded by the AAIB.

The GPS logging function was set up such that position recording for each new flight commenced once the groundspeed exceeded 20 kt. This first recorded position located the aircraft at the eastern end of Spanhoe Runway 27 at 1527:27 hrs. Eight further track points were recorded as illustrated in Figure 3.

Footnote

[3] Immediately south of the south-western tip of Rutland Water.

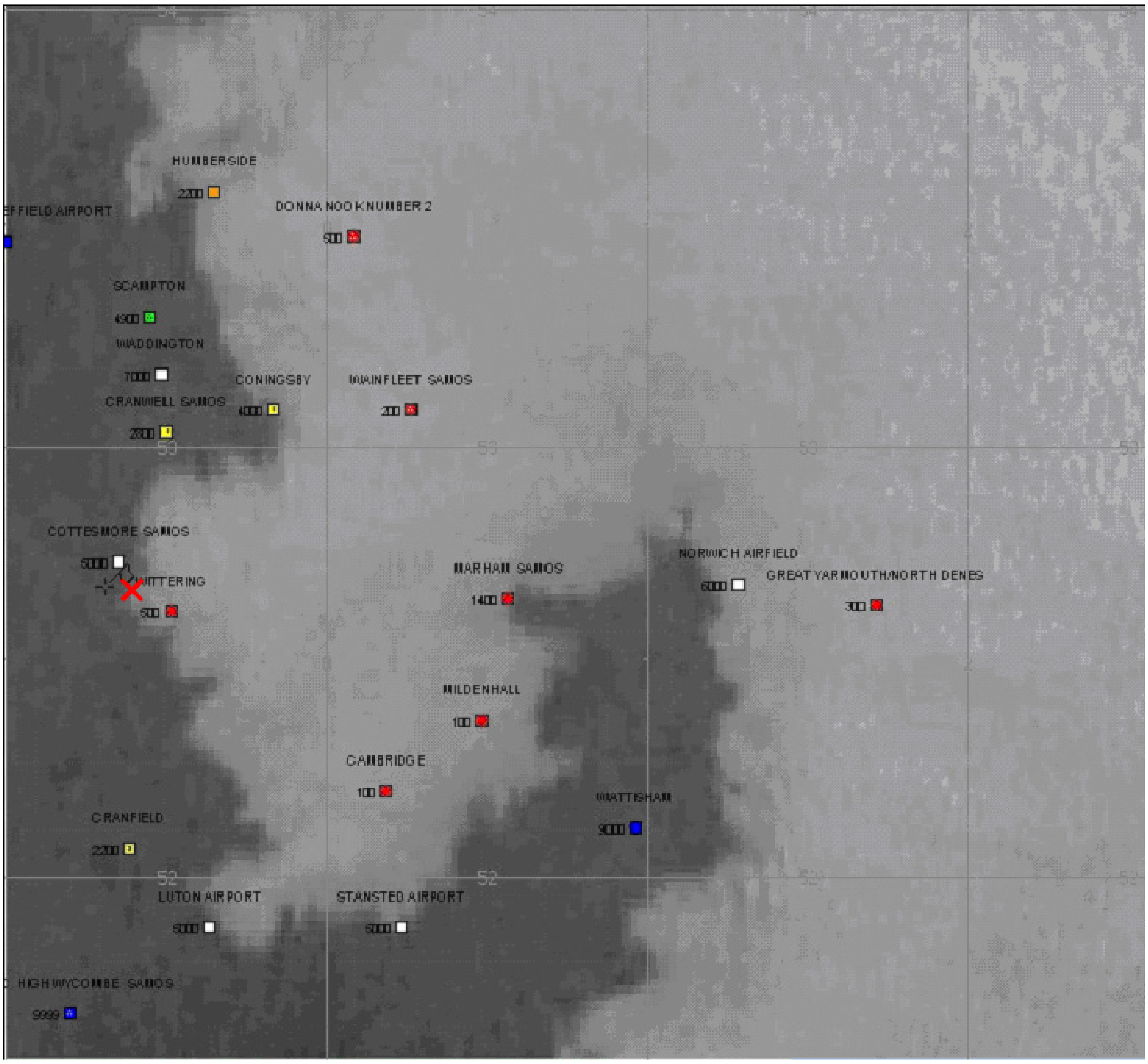


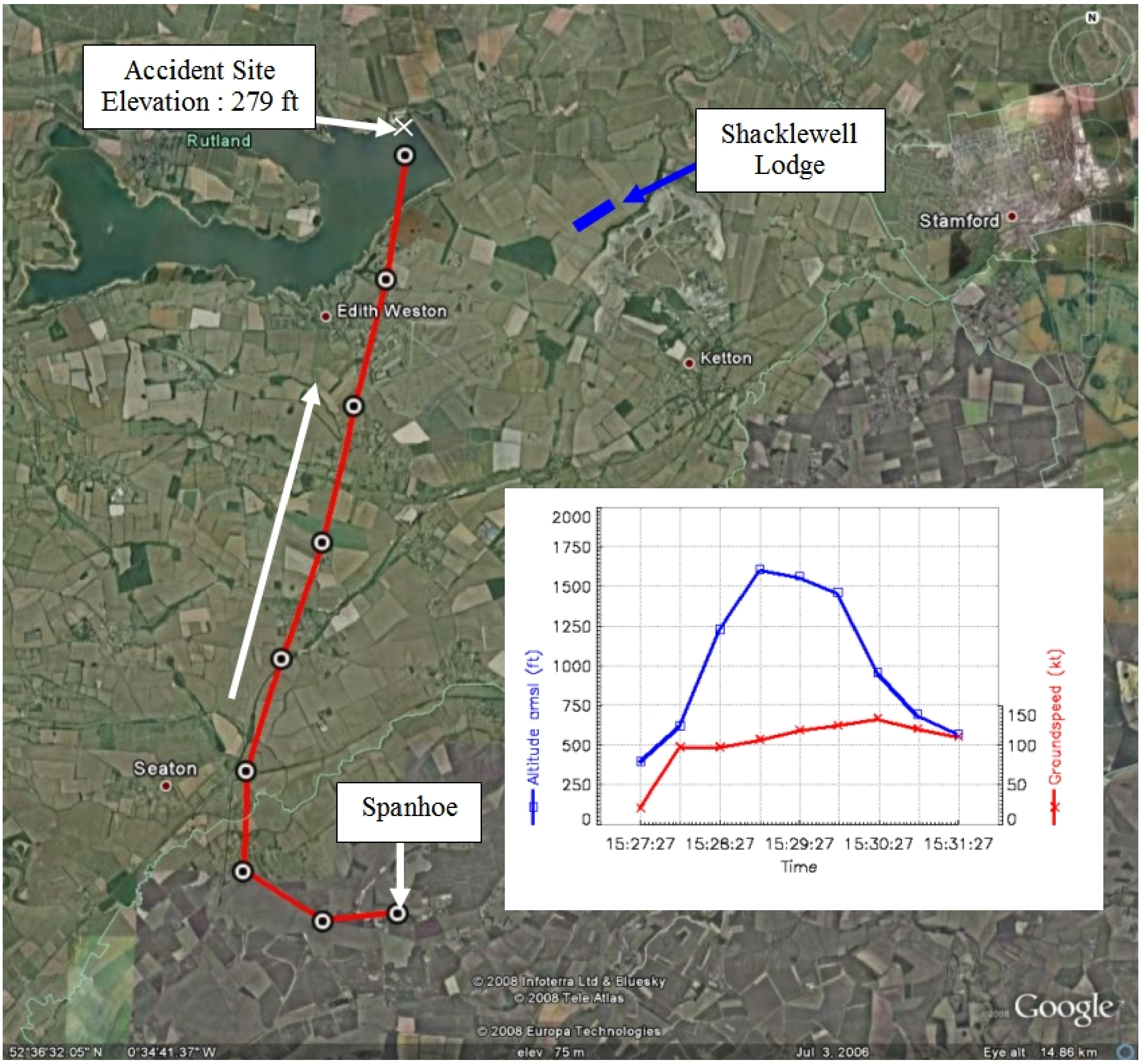
Figure 2

Visible cloud satellite image taken at 1530 hrs on 13 February 2008, five minutes before the accident. The approximate location of the accident site is marked X

The recorded GPS altitude was based on the WGS84 coordinate system. This was converted to altitude above mean sea level (amsl) which showed a GPS altitude at Spanhoe of 394 ft amsl. The eastern end of Spanhoe's Runway 27 is at an elevation of around 344 ft. This suggests that the recorded GPS altitude was in error by around 50 ft at the start of the flight.

GPS altitude can be subject to substantial error and is typically less accurate than altitudes derived by barometric means. This error can arise from a number of sources, including the number of satellites in view of the receiver, satellite orientation and operability, and the GPS approximation of the geodetic model of the earth. The 50 ft inaccuracy at Spanhoe is not unusual and it is likely that all the other recorded GPS altitudes were subject to an error of this magnitude. Horizontal GPS position is usually subject to less error.

After departing Spanhoe, G-BKFZ climbed, turned to the right and headed towards the eastern shore of Rutland Water. The maximum altitude achieved was



(Google Earth ™ mapping service/Infoterra Ltd & Bluesky / Teleatlas / Europa Technologies)

Figure 3

G-BKFZ ground track and altitude from GPS data

1,607 ft amsl, after which a descent commenced of about 150 ft/min which lasted for about one minute. Thereafter, it increased to about 1,000 ft/min. Between the penultimate and final GPS recorded position, the aircraft descended from 696 ft to 572 ft in 31 seconds; a descent rate of 240 ft/min. The total distance covered between these positions was 1 nm, which suggests a descent slope of around 1:50.

The final recorded position of the aircraft was at 1531:27 hrs, at an altitude of 572 ft amsl, at an instantaneous groundspeed of 111 kt and an instantaneous track of 000°. Using the 500 ft aftercast wind of 060° at 11 kt, this represented an airspeed of around 117 kt. This position was approximately 440 m from the accident site where the terrain elevation was 279 ft. Extrapolating from the last GPS point to the accident site gives a final average descent slope of about 1:5 and an approximate final average vertical speed of 2,300 ft/min down. However, it should be emphasised that, due to the inherent inaccuracies associated with GPS altitudes and the 30 second period between data points, the calculated values quoted above for vertical speeds and descent ratios should be treated as very approximate values.

Accident site examination

The accident site was located among trees in a park on the north-eastern edge of Rutland Water and was 279 ft amsl. The aircraft's initial impact was with two trees, 6.6 m apart, whilst in a bank to the left of approximately 20° and about 12 ft above the ground, Figure 4. The impact removed the aircraft's left and right wing outer sections; it continued and struck the ground 15.5 m from the trees whilst on a track of 342°(M). The aircraft's final trajectory from the trees to the ground was calculated at between 10° and 14° below the horizon[4]. After striking the ground, the fuselage bounced and hit another tree head-on, causing the aircraft to break up into multiple sections. The furthest item of wreckage was the battery, which had travelled 127 m from the initial impact point. There were three propeller slash marks at the ground impact point spaced 40 cm apart.

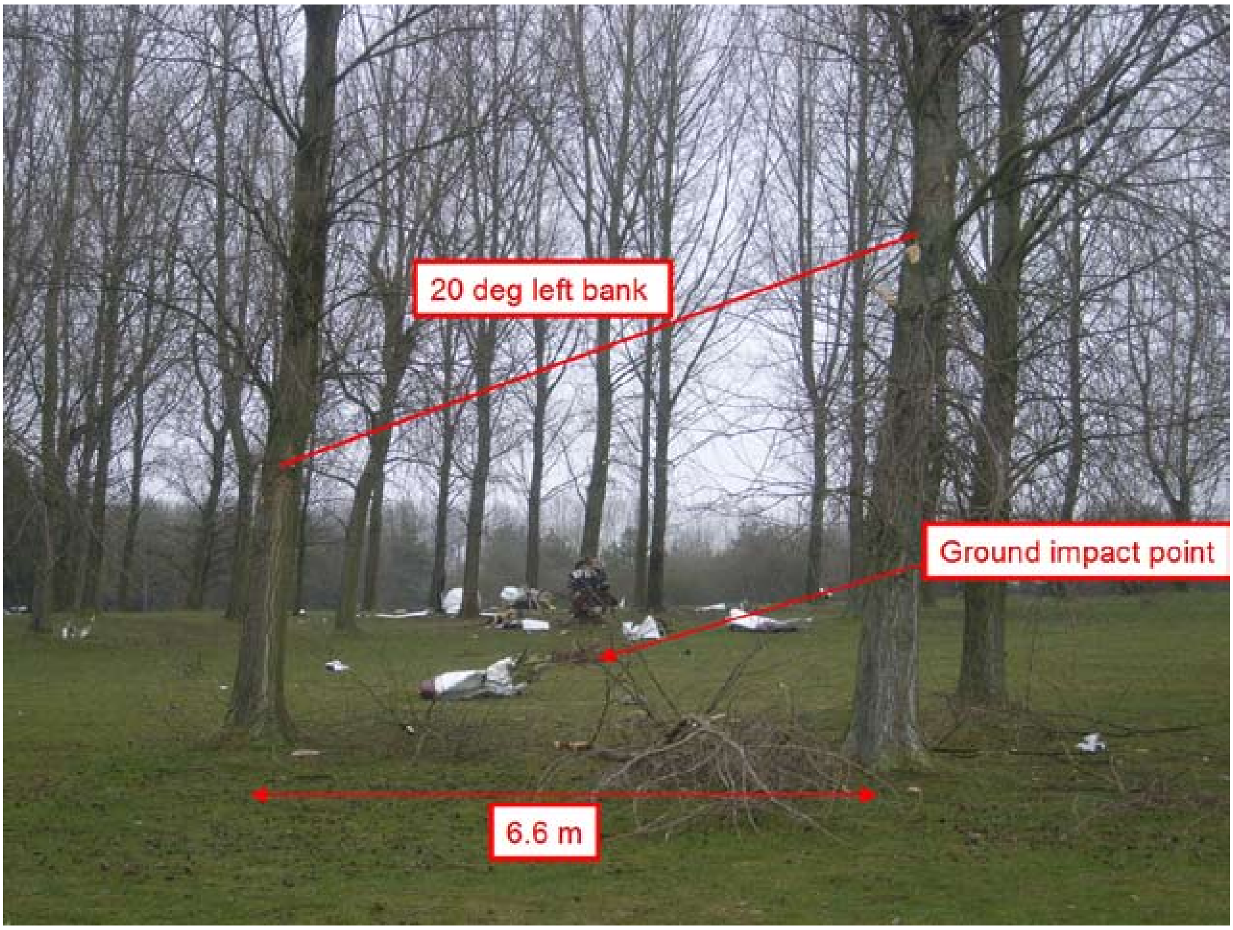


Figure 4

Accident site, viewed in the direction of flight, showing initial impact with trees and ground impact point

Footnote

[4] It was considered unlikely that the tree impact altered the aircraft's trajectory significantly.

Initial wreckage examination

The main and nose landing gear legs were found in their retracted positions. The right inboard wing had separated from the fuselage at the spar join, and the right wing fuel tank had ruptured; only a small amount of fuel was found in this tank. The left inboard wing was attached to the remaining section of centre fuselage, and the lower skin of the wing fuel tank had split; no fuel was found in this tank. Samples of soil from beneath both fuel tanks were tested for contamination by fuel, but the results were inconclusive.

The engine had separated from its mounts and had tumbled along the ground. The three propeller blades had leading edge indentations and chord-wise scratches near their tips.

All the major aircraft structural components were accounted for and no evidence was seen of any pre-impact failures. Following the on-site examination, the aircraft wreckage was recovered to the AAIB's facility at Farnborough for a more detailed examination.

Detailed wreckage examination

Flight controls

The roll controls on this aircraft type consist of two interconnected control wheels that are linked to the ailerons through a series of torque tubes, sprockets, chains, control cables/pulleys and bellcranks. Pitch control is effected by an all-moving stabilator, connected to the control wheels through a series of cables/pulleys and push-pull rods. Numerous separations were present within both of these control systems, but all were attributable to overload failures consistent with the break-up of the airframe. No evidence was seen of any pre-impact disconnection(s). The stabilator trim jack screw was found in a position corresponding to full nose-down trim. However, as the controlling cables had failed in overload, it would be typical that one cable would have failed before the other, causing the screw to be driven to one extreme of its travel. The rudder control cables were connected at both ends but had also failed in overload, consistent with occurring during the airframe break-up. The flap lever was found in the flaps fully down position but the lever had been bent in that direction and did not represent a reliable pre-impact position. No other evidence was found of the position of the flaps at the time of impact.

Instruments

The flight and engine instruments had all suffered damage and many of the instrument faces had separated from their casings. The instrument faces were examined for witness marks of any needle positions at the time of impact; no reliable marks were found. The main altimeter subscale indicated a pressure setting of 1018 mb, the standby altimeter setting was 1024 mb. Both altimeters had suffered impact damage and could not be tested. The Horizontal Situation Indicator (HSI) was intact and indicated 320° with the heading bug set to 040°. The Attitude Indicator's face and casing were damaged, although most internal components were undamaged. The casing that surrounded the gyroscope rotor had evidence of rotational scoring, and the rotor spun up and the instrument self-erected when compressed air was applied to the device.

Some of the warning and indication light bulbs were recovered intact and were examined under a microscope to determine if any lights were illuminated at the time of impact. The bulb for the '*Gear in Transit*' light and the bulb for the gear '*Auto Ext Off*' light both had clear indications of stretched filaments, and were therefore probably illuminated at impact. The bulb filament from the oil low pressure warning light had not stretched and was, therefore, probably off at impact. The bulb filament for the Alternator ('*Alt*') warning light had a minor amount of stretch, but this was insufficient to draw a firm conclusion on its status at impact. The '*Gear Unsafe*' light and the '*Right Gear*' down-and-locked light were determined to have been off at impact. No other bulbs were recovered.

Fuel System

No fuel was recovered from the empty left tank which had split, and a small amount of fuel remaining in the ruptured right tank was lost when the wing was lifted. However, a small sample of fuel was recovered from the engine-driven pump and this was tested and found to conform to the properties of AVGAS 100LL; there was no evidence of contamination. The fuel tank selector was found set to the right tank and the fuel filler cap seals were in satisfactory condition.

The engine-driven fuel pump had split in to two pieces and could not be tested, but the drive pin had not sheared which indicated that the pump had not seized in flight. The electric fuel boost pump was connected to a 14 VDC power source, but did not operate. The pump was separated from the motor and the motor was re-connected to the power source, but it still did not operate. The motor case was opened up, which revealed a warped washer around the bearing and a build-up of dust. There was some friction when rotating the motor by hand but it did not appear excessive. When the motor was re-assembled and connected to the power source, the motor operated normally. No fault could be found that would explain why the motor did not originally operate, as it was considered that the warped washer would not have prevented rotation. The pump had suffered significant impact damage, and although it could be rotated by hand, the motor had insufficient torque to turn it.

The fuel lines from the fuel tanks to the fuel selector were continuous apart from a separation at the right wing-to-body join. In this separated location, where the centre fuselage fuel pipe joined the right wing fuel pipe, it was apparent that a repair had been made, Figure 5. The two plain-ended pipes had been connected with a 12 cm long rubber hose held in place with a single jubilee clip at each end. According to the aircraft manufacturer, this was not an approved method of repair and there should have been a metal threaded union connecting the two pipes in this location. It was determined that the overlap that would have existed between the fuel pipe from the right tank and the rubber hose was approximately 1 cm.

The fuel hose between the engine-driven fuel pump and the fuel injector body had a loose connection at the injector body end but, because both the pump and injector had separated from the engine, the loosening could have occurred during the impact sequence. The fuel hose from the injector body to the fuel manifold had failed in overload. The gascolator had been crushed and was split open; no fuel was present inside.

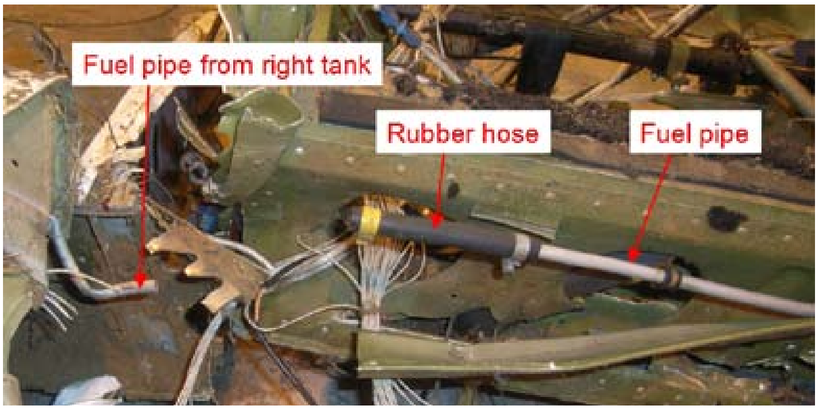


Figure 5

Rubber hose repair to fuel pipe

Other component examinations

The throttle and mixture control levers were close to the full forward position and the propeller lever was in a mid position, but the disruption and damage to the throttle quadrant made these unreliable indications of their pre-impact positions. The magneto switch was set to the RIGHT magneto and the key had broken off. The battery, alternator and the electric fuel boost pump switches were in the ON position. The 'Alternate Air' lever was in the ON position but this was considered an unreliable indication of the pre-impact position. The COM 1 radio was selected ON and was set to 130.2 MHz, the RAF Cottesmore frequency. The combined pitot/static probe had separated from the wing and while the pitot tube hole was plugged with mud and the static port was clear. The pitot-static plumbing system was too severely disrupted to enable any useful determination of its condition prior to the accident, although all damage seen appeared consistent with having occurred during the impact. The electrical wiring from the cockpit area was examined and no evidence was found of any electrical arcing or sooting.

Powerplant examination

The engine and propeller were taken to an approved overhaul facility for strip examination. The engine had suffered significant impact damage, including separation of the No 4 cylinder head from the cylinder barrel. The engine crankcase was disassembled and no internal defects were found.

The left magneto, oil filter, engine-driven fuel pump and propeller governor had all separated from the engine accessory gearbox, and exhibited varying degrees of damage. The fuel injector servo unit had also separated from the engine. The injector and fuel manifold were stripped and all internal components were in satisfactory condition. The engine could be rotated freely by hand, although the damaged No 4 cylinder prevented full rotation. The engine had been sufficiently lubricated and there was no evidence of any pre-impact mechanical failure or evidence of overheating. The spark plugs were in satisfactory condition, apart from the lower No 2 plug, which was coated in oil, and the upper No 4 plug, which had disintegrated at impact. The right magneto was still attached but its retaining nuts were loose but as their washers had evidence of torque having been applied, it was possible that the nuts loosened as a result of impact forces. The engine timing was checked and was found to be correct within the range of movement of the loose right magneto. Both magnetos were rig tested and operated normally. The oil filters were clean and the oil scavenge pump was in satisfactory condition. The vacuum pump rotated freely and an internal examination revealed that the rotor and vanes were intact. The propeller governor could be rotated, although it was stiff as a result of impact damage. The alternator could not be tested due to its impact damage.

The propeller hub was disassembled, which revealed that all three blade pitch-links had sheared in overload. The piston rod was slightly bent and the pre-load plates did not exhibit any witness marks that could be used to determine the blade angles at impact. There was sufficient grease within the hub and no evidence of any pre-impact failure. All three propeller blades were bent aft from the shank to the tip. Propeller blades No 2 and No 3 were also twisted towards low pitch. This evidence, coupled with leading edge indentations and chord-wise scratches on all three blades, indicated that the propeller had significant rotational energy at impact.

Additional information

Since the propeller was a variable-pitch constant-speed unit, evidence of rotational energy in itself did not indicate that the engine was producing power. At high airspeed, such a propeller may be turning at relatively high speed, but at relatively low, or no, power. The spacing between the three propeller slash marks found in the ground was 40 cm and this was used to determine a relationship between the propeller's rotational speed and the aircraft's groundspeed. This relationship for a selection of groundspeeds is shown in Table 1.

V_{GS} (kt)	RPM
80	2062
90	2320
100	2578
110	2835
120	3093

Table 1

Relationship between groundspeed (V_{GS}) in kt, and propeller speed (RPM) for 40 cm spacing between propeller slash marks for a 3-bladed propeller

As no pre-impact defects were found with the propeller governor, and the propeller speed is limited to 2,700 rpm, the aircraft was therefore unlikely to have had a groundspeed at ground impact above, approximately, 105 kt. The degree of disintegration and the spread of the wreckage following ground impact, were consistent with speed of at least 80 kt when the aircraft struck the ground, so it is probable that the propeller speed was between 2,000 rpm and 2,700 rpm. A rotational speed above 2,000 rpm is also considered consistent with the damage sustained by the propeller blades. However, a flight conducted with a similar aircraft has shown that a propeller speed of 2,000 rpm to 2,200 rpm can be achieved at 110 kt to 120 kt in a descent with idle power. Therefore, it was not possible from the propeller speed evidence alone to establish that the engine was producing more than idle power.

Maintenance history

On 28 December 2007, the pilot flew G-BKFZ from Shacklewell to Spanhoe for its annual maintenance check. The aircraft's Certificate of Airworthiness was due to expire on 3 January 2008 and the aircraft required a Star Annual check before the CAA could issue a new EASA non-expiring Certificate of Airworthiness (CoA) and the accompanying Airworthiness Review Certificate (ARC).

The maintenance for the Star Annual check was carried out under the supervision of a Licensed Aircraft Engineer (LAE), at Spanhoe. In addition to the normal inspections, the two magnetos were removed for a 500 hour inspection, and re-installed, and a new propeller was fitted. The landing gear hydraulic hoses, two fuel hoses and two oil hoses were also replaced. A special inspection for cracks of the stabilator balance weight arm, required by an EASA Airworthiness Directive, was also carried out, but no cracks were found. As part of a previous Annual inspection, the two altimeters had been checked for accuracy. The maintenance worksheet recorded that the main altimeter indicated 0 ft and 500 ft at reference pressure altitudes of 0 ft and 500 ft respectively, while the standby altimeter indicated 10 ft and 480 ft. This was within acceptable limits.

Approximately two or three gallons of fuel were removed from the aircraft by the engineer to clean the engine. Additionally, fuel from the aircraft was also used to verify the flow rate through the new fuel hoses.

The aircraft's 50 hour/6 month maintenance checks were carried out by the pilot in accordance with the applicable Light Aircraft Maintenance Schedule (LAMS), the last such check being on 11 September 2007.

The British Civil Air Regulations (BCAR) state in Section A:

> *'A Star Inspection and the coincident annual inspection shall be carried out at the premises of an organisation approved in accordance with BCAR Chapter A8-15…'*

A maintenance organisation that is approved in accordance with BCAR Chapter A8-15 is identified as a M3 organisation, but the organisation at Spanhoe was not so approved. The LAE at Spanhoe stated that he thought that the maintenance work for the Star Inspection could be carried out at a non-M3 organisation, on condition that the final check was carried out, and paperwork signed off, at an M3 approved organisation.However, this is incorrect as this inspection must be carried out at the premises of an approved organisation. The engineer completed the Annual check and signed it off in the aircraft logbooks on 31 January 2008 and, sometime between 5 and 7 February 2008, he flew G-BKFZ to a M3 approved organisation at Seething. Here, the Chief Engineer of this organisation carried out a physical audit of the aircraft and completed the appropriate paperwork to apply for the new EASA Standard CoA and ARC; both were issued on 13 February 2008.

Sometime between 7 February 2008 and the accident date, 13 February 2008, the engineer from Spanhoe flew G-BKFZ back to Spanhoe. The Star Annual maintenance check included an inspection of all the fuel pipes and fuel hoses in the aircraft, and should have revealed the presence of the non-approved fuel pipe repair in the right wing to fuselage join area. However, the engineer at Spanhoe stated that he thought the rubber hose had been installed as an anti-chafing device and did not realise that there would normally be a union in this position.

The airframe logbooks, dating back to 1994, contained no entries for a fuel pipe repair. The Service Bulletins and Airworthiness Directives with their relevant compliance due dates were recorded in the pink sheets of G-BKFZ's engine logbook, but these had not been recorded in the airframe logbook following the aircraft's Annual Inspection.

Altimetry and terrain

Shortly before the accident, the pilot had requested the Wittering QFE from the approach controller at RAF Cottesmore; the similarity between the elevations of RAF Wittering and Shacklewell, together with their proximity, meant that the RAF Wittering QFE would have served as a workable QFE for Shacklewell Lodge. In fact, the controller passed the Cottesmore QFE, as RAF Wittering was closed. RAF Cottesmore's elevation is 461 ft and RAF Wittering's, 273 ft.

The aircraft's main altimeter was found set to a pressure datum of 1018 mb, only 1 mb displaced from the Cottesmore QFE passed to the pilot by ATC; however, this discrepancy is not considered significant and may have resulted from the impact or slight imprecision in adjusting the subscale. The pressure datum of the standby altimeter was found set to 1024 mb and, as this was consistent with the QFE at Spanhoe, it seems likely that the altimeter had been set to zero before departure.

Post-mortem examination

A post-mortem examination of the pilot was carried out by a specialist aviation pathologist. He found no sign of pre-existing medical condition which might have contributed to the accident. There was some evidence to indicate that the pilot had been holding the controls at the time of impact.

Analysis

GS data

The last four GPS data points indicate a progressive reduction in the aircraft's rate of descent, which began at approximately 1,000 ft/min at an altitude of around 1,450 ft. For a minute prior to this, the aircraft had been in a gentle descent of around 150 ft/min, having achieved a maximum altitude of 1,607 ft, and at which time the pilot was above cloud and communicating with RAF Cottesmore. If the top of the cloud/fog layer was between 500 ft and 700 ft at that time, as reported later by the police helicopter, then the aircraft would have entered the cloud/fog whilst descending at approximately 500 ft/min and with a groundspeed of around 130 kt.

The last two GPS points indicated that the aircraft travelled a distance of 1 nm in 31 seconds while descending only about 125 ft; this represents an approximate rate of descent of 240 ft/min and a very shallow average descent of around 50:1. This would not be achievable in this type of aircraft without some engine power, even taking into account the slight reduction in airspeed at this time.

From the analysis of the accident site and the spread of the wreckage, the aircraft's speed was estimated to have been in excess of 110 kt when it struck the trees. The aircraft's final trajectory from tree impact to ground impact was 10° to 14° below the horizon which represents a descent rate of between 1,900 ft/min and 2,700 ft/min at an airspeed of 110 kt. These values were broadly consistent with the final 2,300 ft/min descent rate extrapolated from the last GPS data point, although this value must be treated as approximate due to the inherent inaccuracies with GPS derived height data. Despite these inaccuracies, the combined data suggests that a marked increase in the rate of decent of the aircraft occurred shortly before it struck the trees.

Engineering aspects

The landing gear was established to have been retracted at impact so it is possible that the 'Gear in Transit' light was activated as a result of the inboard right wing separation severing the wires to the right gear microswitches. The 'AUTO EXT OFF' light illuminates when the automatic gear extension system is disabled; and it is not uncommon for pilots to disable this system for flight. The significant conclusion from these two bulbs having been illuminated is that electrical power was available on the aircraft at the time of impact.

There was no evidence of any pre-impact structural failure or a pre-impact problem with the flight controls. As far as could be determined, the vacuum pump and Attitude Indicator were functioning correctly prior to impact and, therefore, artificial attitude reference should have been available to the pilot.

The engine examination revealed no evidence of pre-existing defect or failure. The loose right magneto was probably caused by impact forces but, should it have been loose prior to impact, it would have caused rough running which could have been resolved quickly by the pilot isolating this magneto by selecting the magneto key to LEFT. This was found set to RIGHT, which would suggest that the right magneto was operating correctly; however, the key had broken off during the impact so it was possible that impact forces could have moved the key to the RIGHT position.

It could not be established from the accident site whether there had been sufficient fuel onboard the aircraft prior to impact for continued flight; however, fuel was recovered from the engine-driven pump which indicated that fuel was probably being delivered to the engine at the time of impact. The examination and test of the electric fuel boost pump proved inconclusive, but the engine-driven pump alone would have been sufficient to provide adequate fuel flow under normal conditions. The fuel selector was set to the right tank and it was within the fuel line from the right tank that the non-approved rubber hose repair had been carried out. The fuel pipe was found separated from the hose and, although it was not possible to establish conclusively when this occurred, it was considered unlikely to have occurred before the impact, as the fuel pipes would have been secured to the airframe and not likely to pull apart. Also, there was evidence that the pipe from the wing had been inserted by at least 1 cm into the hose, and both screw clamps were not judged to have been loose. However, had the pipe separated, or had been close to separating from the hose in flight then, either a loss of fuel flow or entrained air could have resulted in partial or a complete loss of power. Apart from this possibility, no other evidence was found during the engineering investigation that could be considered a causal factor in the accident.

Operations aspects

Shortly before the accident, the pilot reported to the approach controller at RAF Cottesmore that he was flying at 1,200 ft just above a cloud layer. Data from the Met Office indicated that the aircraft must have been flying close to the boundary between clear skies with haze/mist to the west, and very poor visibility and low cloud conditions, with mist, fog and hill fog, to the east. A few moments later, the aircraft descended into the cloud which was continious to ground level, and crashed into trees before striking the ground.

With the proximity to relatively clear air, where an emergency or precautionary forced landing could have been attempted, three possible reasons for the aircraft to descend in to cloud are listed below, and are considered in turn:

- the pilot intended the aircraft to descend
- the pilot did not intend the aircraft to descend but lost control of the aircraft
- the pilot did not intend the aircraft to descend but the aircraft was no longer capable of sustaining level flight.

Intentional descent

Although the pilot did not hold a current IMC or Instrument Rating, and was therefore not qualified to fly in cloud, the fact that he had logged instrument flight time after his IMC rating had expired, may indicate that he had confidence in his ability to control the aircraft by sole reference to instruments. The pilot was aware, prior to flight, that foggy conditions were expected. He had received the RAF Cottesmore weather report which indicated 5,000 metres visibility and a clear sky; this might have influenced him to think that he was flying above a layer of cloud rather than a layer of fog and indeed, his radio transmission mentioned 'cloud' rather than fog. He may, then, have considered that flight below the cloud would be possible.

If it was the pilot's intention to descend through the 'cloud' in order to locate his destination visually and land, it would be logical and practical for the aircraft's path to have turned towards the destination at some point, as the pilot had a GPS receiver with him capable of showing the necessary route. However, the aircraft's track was essentially straight and towards the eastern end of Rutland Water and it could equally well be that his intention was to descend to a low height over an area free from obstructions, or that he only intended to maintain control of the aircraft in a straight line when in IMC , possibly hoping to become visual with the ground in time to divert to Shackwell lodge.

However, as he descended into the 'cloud', he would have seen his altimeter read closer and closer to zero, and then pass through reading zero very soon before impact. The forward speed and the significant rate of descent just prior to impact, gear and flaps up, would not be consistent with the normal actions of a pilot who knew that his aircraft was close to the ground with the ability to climb back to a safe height. Therefore, it is considered unlikely that the pilot deliberately descended to a dangerously low height in fog. His initial intention may have been to get below the 'cloud' layer, and complete the journey in sight of the ground, but he did not appreciate the high rate of descent until it was too late to recover.

Loss of control

Loss of control, resulting from, for example, incapacitation, distraction or spatial disorientation, often result in the aircraft entering a spiral dive. The relatively large time intervals between the positions recorded by the pilot's GPS unit, make determination of the aircraft's precise track impossible, but small deviations from a straight path may have been present between data points. However, the last seven position data points are essentially in a straight line, and it is therefore considered improbable that any significant deviations from a straight descending path occurred, and hence that the aircraft was not out of control whilst in cloud. Should a loss of control have occurred above the cloud, which forced the aircraft to descend in to the cloud, then it would not seem reasonable for the aircraft to have continued to descend essentially in a straight line until it crashed, rather than crashing sooner, or recovering to controlled flight above cloud. The fact that the aircraft struck the trees in a reasonably upright attitude also suggests that it was under control at the moment of impact. This view is supported by the findings of the post-mortem examination which identified that the pilot was probably handling the controls at the moment of impact.

The pilot previously held an IMC rating, and must have demonstrated his ability to fly on instruments in order to obtain and renew that rating. The aircraft was equipped with adequate instrumentation to permit flight in IMC, and the engineering examination identified as far as possible that this equipment was serviceable, and that electrical power was available. Again, the fact that the pilot had logged some instrument flight time after his IMC rating had expired, may indicate that he had a measure of confidence in his ability to control the aircraft by sole reference to instruments, even though he had flown for only two hours in the last 90 days, and could not be considered to be current at flying on instruments.

The post-mortem examination did not identify any medical cause for the accident, in terms of incapacitation. If anything, it indicated against this to some extent. However, the possibility that the pilot suffered some sort of brief incapacitating event, which prevented his controlling the aircraft for a very short time, cannot be ruled out.

A distraction, requiring a significant element of the pilot's attention, remains a possibility. Concentrating on some task, he might have kept the aircraft under control, without being able to assess his position (particularly in terms of his altitude) and make precise corrections to achieve his desired flight path. The most likely cause of distraction is considered be an unidentified technical malfunction of some kind.

It could be argued that the absence of an emergency communication to ATC might indicate that the pilot did not recognise the gravity of his situation. However, communications with ATC often assumes a lower priority to a pilot than resolving a difficulty and, therefore, the absence of communication is not considered significant.

It is concluded that it was unlikely the pilot lost control of the aircraft prior to the accident.

Aircraft malfunction

The analysis of the wreckage concluded that a major failure or malfunction of the aircraft structure and systems was unlikely to have occurred.

The aircraft departed with a small quantity of fuel on board, apparently sufficient to complete the flight but offering an endurance of, at most, one hour. Depending upon the distribution of the fuel, it is possible that one fuel tank may have run dry, causing the engine to falter or stop. Although not considered likely, the possibility that a separation of the fuel hose from the right wing pipe could have been a factor in the accident could not be dismissed entirely. In this event, the pilot would have found it necessary to select the other tank and restart the engine. The 'as found' positions of the fuel pump switch and magneto switch are consistent with attempts being made to deal with an engine problem. The pilot's flying experience may have enabled him to diagnose a problem accurately and, perhaps, attempt to resolve it. Some witnesses spoke of hearing the engine running, whilst others spoke of hearing abnormal engine sounds. It is therefore unclear whether he had actually suffered an engine problem.

Faced with a loss or significant reduction of engine power, the pilot would have had no option but to descend in order to maintain flying speed. In this circumstance, it might be expected that he would have turned the aircraft towards the clearer air, in the hope of flying out of the fog before reaching the ground, unless he was focussed on trying to resolve a problem. Equally, it is possible that he may have considered heading for Rutland Water to land/ditch in an area without obstructions. The impact speed, estimated at in excess of 110 kt, mitigates against this unless, as previously stated, he was focussed on trying to resolve a problem. Another possibility was that, having descended into the fog, the pilot may have only been able to cope with maintaining control of the aircraft in a straight line as a result of his lack of currency when flying solely on instruments.

In conclusion, it is considered that the pilot may have been forced to descend in to the fog, possibly due to a loss of engine power.

Conclusions

The aircraft crashed as a result of hitting trees in foggy conditions. The reason for the aircraft's descent in to the fog could not be clearly established, but various possibilities were identified.

ACCIDENT

Aircraft Type and Registration:	Piper PA-34-200T Seneca II, G-ROUS
No & Type of Engines:	2 Continental Motors Corp TSIO-360-EB piston engines
Year of Manufacture:	1978
Date & Time (UTC):	12 November 2008 at 1525 hrs
Location:	Oxford Kidlington Airport
Type of Flight:	Training
Persons on Board:	Crew - 3 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	Damage to left landing gear retraction mechanism, left wing tip, left aileron hinge bracket, left aileron and flap
Commander's Licence:	Commercial Pilot's Licence
Commander's Age:	47 years
Commander's Flying Experience:	2,684 hours (of which 965 were on type) Last 90 days - 87 hours Last 28 days - 39 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot and further investigation by AAIB

Synopsis

Whilst flying a routine training circuit, the occupants heard a loud bang as the landing gear extended and the 'gear unsafe' warning light remained illuminated. When the aircraft landed, the left main gear leg collapsed and the aircraft departed the runway. It was later identified that the retraction fitting had failed.

History of the flight

The aircraft departed from Oxford Kidlington Airport for a 30-minute training flight with the instructor in the right-hand seat and student pilots in the left and rear seats. The departure and initial climb into the Runway 19 circuit were flown by the student and apparently passed without incident. After the aircraft had turned downwind the student attempted to lower the landing gear. As the main gear deployed there was a loud bang. The green 'gear down and locked' indication lights illuminated for the right main and nose gear but not the left main gear. The red 'gear unsafe' warning light also remained on. The instructor told the student pilot to continue flying the circuit as normal. Once the aircraft had turned onto the base leg the instructor recycled the gear up and down, but the gear indication lights returned to the same state. The aircraft continued onto final approach and the instructor informed the tower controller of his problem, requesting a visual check of the gear as the aircraft passed over. Both the tower controller and the pilot of an aircraft located at the runway holding point advised that the gear appeared to be down.

The instructor initiated a go-around and selected the gear UP, but the 'gear unsafe' warning light remained illuminated. Again, the instructor told the student pilot to continue to fly a normal circuit and on the downwind leg he advised ATC of his intention to land this time. During the downwind leg, the instructor confirmed that the indication was correct by interchanging the bulbs from the left and right main gear green lights. At the end of the downwind leg, the instructor used the emergency gear lowering switch to extend the gear, but this made no difference to the cockpit indication. The instructor then became the handling pilot to fly the final approach and landed on the right main gear, attempting to hold off the left main gear for as long as possible. When he felt the left wing drop below its usual orientation, he feathered both props and retarded both the mixture levers. The left wing then contacted the runway and the aircraft veered round to the left, departing onto the grass at relatively low speed, before coming to rest with the tail still over the tarmac. The aircraft was rapidly shut down and all three occupants departed through the rear door.

Landing gear system (Figures 1 and 2)

The aircraft is equipped with a retractable tricycle landing gear, hydraulically extended and retracted by an electrically powered reversible pump. When the gear is 'down and locked' this is indicated by three green lights, located above the gear selector switch. Activation of all three gear down limit microswitches will shut the hydraulic pump off and energise the green lights. A red light at the top of the instrument panel illuminates when the gear is 'unsafe' (neither limit switch has contacted). As engine manifold pressure drops below approximately 14 inches of mercury, and if the landing gear has not been extended, a throttle switch located in the quadrant will actuate a warning horn indicating to the pilot the landing gear is still up. The warning horn will continue to operate until the landing gear is down and locked.

The landing gear is normally extended and retracted by means of the gear selector switch. In the event of hydraulic or electrical system failure the gear can be extended by pulling the free-fall valve, thus bypassing the hydraulic fluid and permitting the gear to fall under gravity. Once the gear is down, a spring maintains the side-brace truss assembly in the locked position until released by hydraulic pressure. There is also a downlock hook which prevents the truss assembly from moving until the gear is hydraulically retracted.

The hydraulic actuator ram for the main gear leg is attached to a retraction fitting. The fitting is located at the top of the truss assembly and is a key component in the extension and retraction system. The spring assembly and downlock hook mechanism are also attached to this fitting. As the hydraulic actuator ram extends, the fitting rotates forward, pushing the truss assembly against the spring pressure until the gear leg is down and the over-centre position of the truss assembly is reached. The downlock hook is also pushed forward by this action until it latches onto the lower truss link. Retraction of the gear works in the opposite sense, with the downlock hook being pulled off the lower truss link, as the retraction fitting and upper truss link rotate back with the retracting hydraulic actuator ram.

Engineering inspection

Inspection of the left landing gear identified that the retraction fitting had failed along three fracture lines (Figure 3). This had resulted in the top sections of the lugs, where the hydraulic actuator eye end and

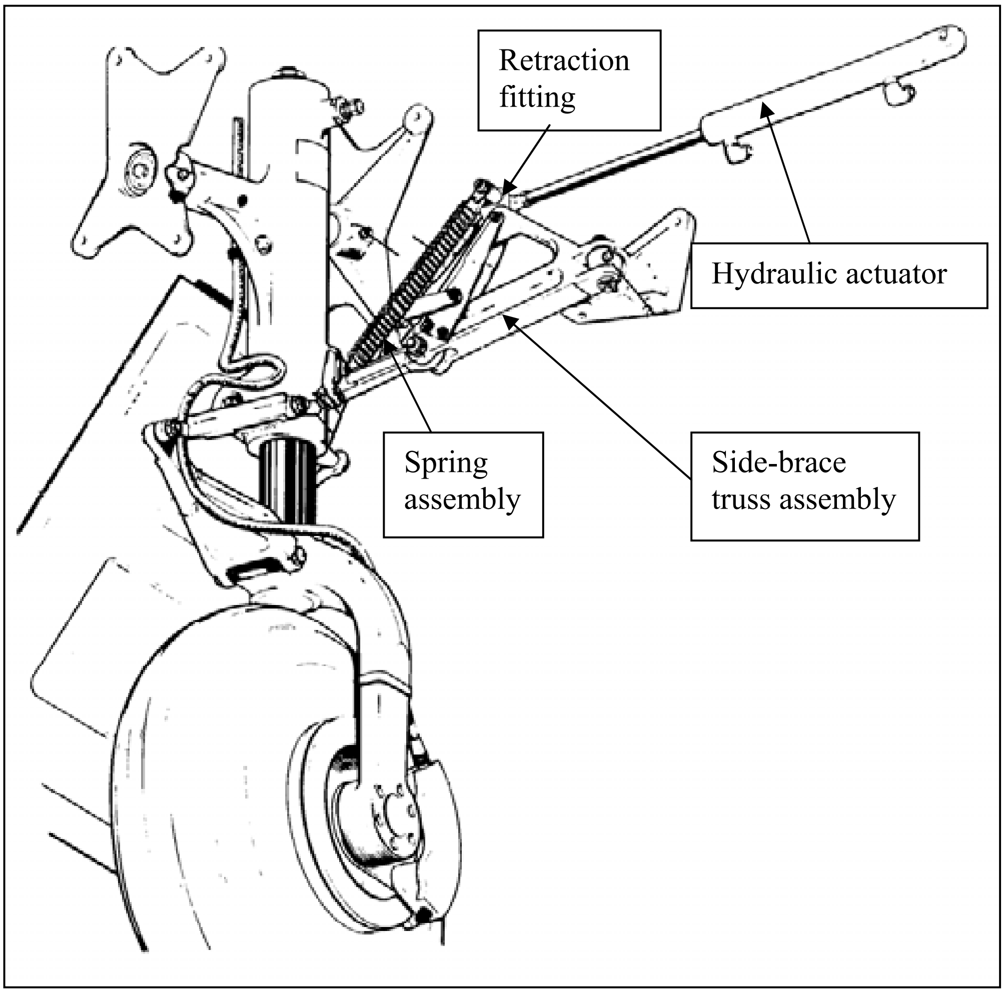


Figure 1

Main landing gear

the spring are attached, separating from the lower half of the fitting, which remained bolted to the truss assembly. A section of the retraction fitting, forward of the attachment point for the downlock hook assembly, was missing completely. The downlock hook assembly had detached from the retraction fitting and was lodged between the down limit microswitch plate and the lower truss link assembly.

Detailed inspection of the retraction fitting identified various impact and wear marks, specifically around each of the bolt holes and on the body of the fitting. A wear mark on the rear under-surface of the fitting also correlated with a witness mark on the truss assembly. The retraction fitting had been installed on the aircraft, as new, three years (1,508 flight hours) previously. The fitting is an aluminium silicon casting and the fracture surfaces had a characteristic granular appearance. The fracture surfaces for failures B and C were significantly darker in colour than for failure A and showed evidence of polishing of the raised sections of the surface.

Analysis

The discolouration and polishing exhibited on the fracture surfaces of failures B and C suggest that these failures occurred prior to failure A. All the fracture

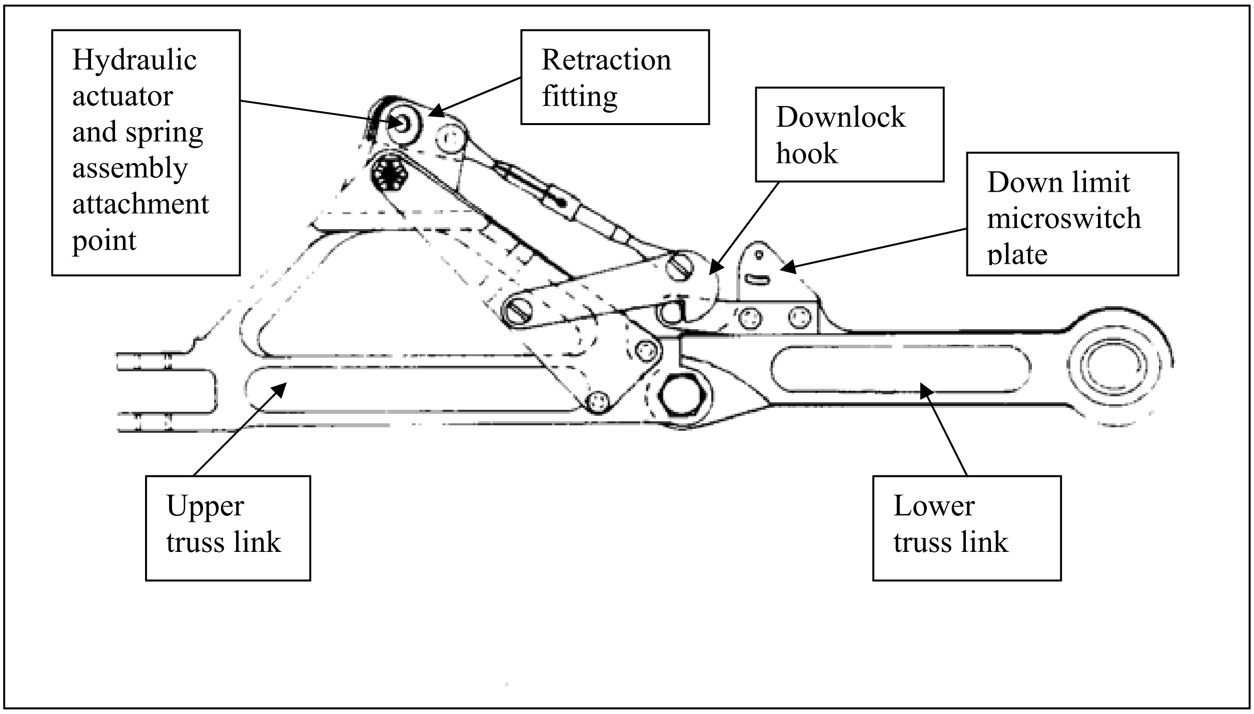


Figure 2

Side-brace truss assembly

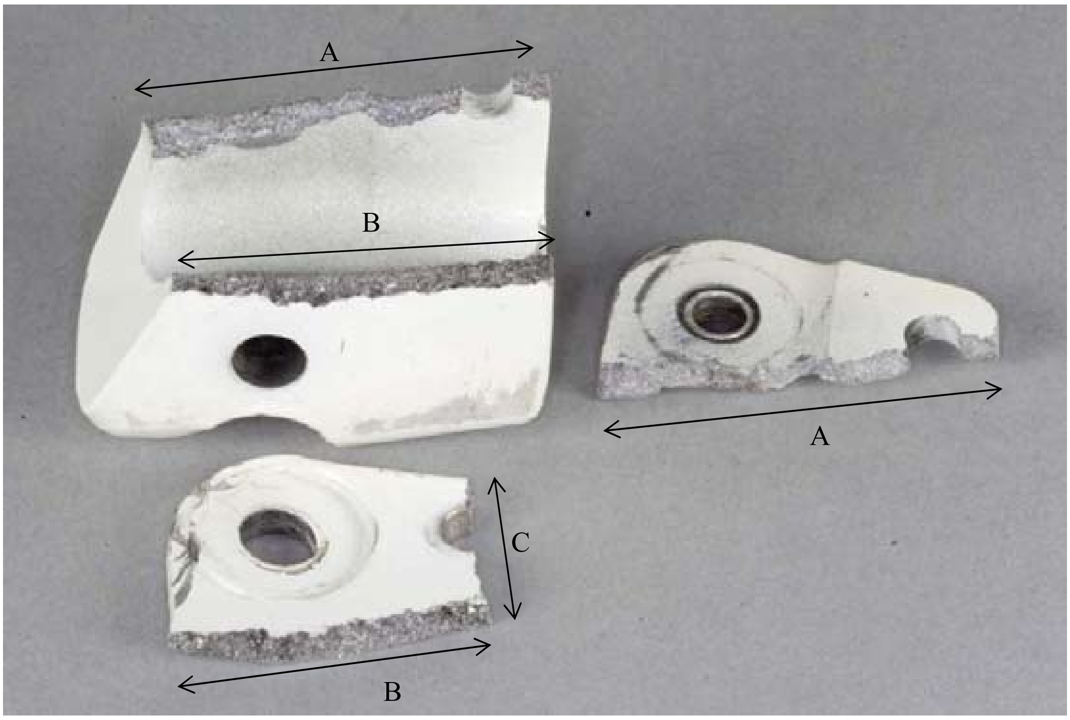


Figure 3

Failed retraction fitting

surfaces were consistent with ductile overload. Cast aluminium has low fracture toughness and is susceptible to shock overload type failures.

Failures B and C probably occurred during a retraction cycle in a previous flight, when the load generated by the downlock hook release was applied to the fitting through the downlock hook assembly for reasons that are not evident. Continued operation of the gear meant that the fitting and downlock assembly would not be working symmetrically, causing the bolt holes in the fitting to wear. This may eventually have resulted in the downlock hook dropping to a lower position than normal during the first extension cycle of the accident flight and, rather than hooking around the 'stop' on the lower truss link, it butted against it. As the hydraulic ram tried to extend the gear fully, the load would be transferred up the downlock assembly and into the remaining intact side of the retraction fitting, causing it to fail in overload and the downlock assembly to drop down.

The gear would therefore have been 'down' as observed by the tower controller and holding pilot. However, the lack of hydraulic actuator connection or downlock hook securing the side-brace truss meant that it was not over-centre and not locked, leading to the cockpit indication observed by the instructor. When the aircraft landed, the unsupported gear leg then collapsed under the weight of the aircraft, trapping the downlock hook assembly as found during the aircraft recovery.

Conclusion

The operator has commenced a fleet-wide inspection programme of the retraction fitting and truss assembly at the next 100 hour maintenance check, with a repeat inspection each annual maintenance check. At the time of writing, six aircraft have been inspected with no adverse findings. The operator also comments that this is the first failure of a retraction fitting in their extensive experience of operating this aircraft type.

ACCIDENT

Aircraft Type and Registration:	Stampe SV4C (Modified), G-BEPC
No & Type of Engines:	1 De Havilland Gipsy Major 10 Mk 2 piston engine
Year of Manufacture:	1946
Date & Time (UTC):	5 April 2009 at 1205 hrs
Location:	Chichester (Goodwood) Aerodrome, West Sussex
Type of Flight:	Private
Persons on Board:	Crew - None Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	Forward fuselage and wings damaged, landing gear detached
Commander's Licence:	Private Pilot's Licence
Commander's Age:	63 years
Commander's Flying Experience:	261 hours (of which 159 were on type) Last 90 days - 21 hours Last 28 days - 8 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

Synopsis

After hand-swinging of the propeller by the pilot, the engine started and accelerated. The aircraft overcame the handbrake and rotated to the right a few times before briefly becoming airborne. The aircraft then contacted trees on the western boundary of the airfield and came to rest, causing significant damage in the process. The pilot stated that he had probably inadvertently closed the 'dummy' mixture lever believing it to be the throttle, thereby leaving the throttle open. There was no body in the aircraft during the engine start to react to the situation and close the throttle.

History of the flight

The pilot had just refuelled the aircraft and positioned it on the grass to the west of the tower. He then leant into the rear cockpit, from the left side, to check that the handbrake was fully on, the rear magneto switch was on No 2, the front magneto switch was on both, a bungee was securely holding the control stick in the fully aft position, the engine throttle was closed and throttle friction was tight. Having completed these checks, the pilot then rotated the oil filter through 90° (standard practice on this engine) prior to commencing an engine start by hand swinging the propeller. There was nobody in the aircraft when the pilot attempted the engine start.

The pilot began to hand-swing the propeller, the engine started immediately and accelerated commensurate with an open throttle. The power produced by the engine was enough to defeat the handbrake, the aircraft moved forward and rotated to the right about its right wheel. After a few gyrations the aircraft became airborne, but it collided with trees at the airfield's western boundary. The aircraft finally came to rest a few metres beyond the western perimeter fence. Significant damage was sustained to the forward fuselage and the wings, both landing gears had separated but there was no fire.

The pilot assessed that, when he reached down into the left side of the cockpit to ensure that the throttle was in the fully closed position, he may have inadvertently operated the 'dummy' mixture lever which is immediately adjacent and to the right of the throttle lever. The throttle is taller and stands proud of the mixture lever to differentiate the two, but the mixture lever serves no purpose as the mixture on the engine fitted to G-BEPC is permanently wired to fully rich.

As the engine is shut down, following a flight, the throttle is routinely moved to fully open as the magnetos are switched off, before then being closed as part of the shutdown procedure. The pilot states that it is possible that the throttle had been left open following the previous flight and that his operation of the 'dummy' mixture lever in the cockpit led to the throttle remaining open when the propeller was subsequently hand swung.

The pilot also stated that he had considered the use of chocks was unnecessary as the engine produces little power at idle.

Discussion

The pilot, in his candid explanation of the sequence of events, states that he most likely operated the wrong lever in the cockpit when he checked if the throttle was in the closed position, leaving the throttle in the open position. The engine was started by the pilot hand swinging the propeller, but there was no body in the cockpit to monitor the engine start. Had there been someone suitably briefed in the cockpit, that person would have been in a position to realise that there was a problem and to react to the situation, closing the throttle and bringing the aircraft to a halt. The lack of a suitably briefed person in the cockpit, during the start sequence, led to the aircraft becoming uncontrollable. In this case the damage was limited to the aircraft itself.

The CAA, in their Safety Sense Leaflet 1 '*Good Airmanship'*, recommend under paragraph 19 *'Starting Engine'*:

> *'b. Never attempt to hand swing a propeller (or allow anyone else to swing your propeller) unless you know the proper, safe procedure for your aircraft and situation, and there is a suitably briefed person at the controls, the brakes are ON and/or the wheels are chocked. Check that the area behind the aircraft is clear.*
>
> *c. Use a Check List which details the correct sequence for starting the engine. Make sure the brakes are ON (or chocks in place) and that avionics are OFF before starting engine(s).'*

ACCIDENT

Aircraft Type and Registration:	Super Aero 45 Series 4, G-APRR
No & Type of Engines:	2 Walter Minor 4-3 piston engines
Year of Manufacture:	1956
Date & Time (UTC):	28 February 2009 at 1619 hrs
Location:	Blackbushe Airport, Hampshire
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - 2
Injuries:	Crew - 1 (Minor) Passengers - 2 (Minor)
Nature of Damage:	Extensive damage
Commander's Licence:	Private Pilot's Licence
Commander's Age:	43 years
Commander's Flying Experience:	239 hours (of which 14 were on type) Last 90 days - 14 hours Last 28 days - 5 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

Synopsis

During takeoff the aircraft swung to the left. The pilot attempted to correct this, inducing an oscillation in yaw. Believing the airspeed to be sufficient for flight the pilot attempted to lift off, after which the aircraft stalled, causing the right wing to strike the ground. The aircraft then came to rest in a gorse bush to the right of the runway.

History of the flight

The pilot lined the aircraft up on the hard surface Runway 25 at Blackbushe Airport in preparation for the return flight to Goodwood. During the takeoff roll, in calm wind conditions and as the tail was lifting, the aircraft began to swing to the left. The pilot attempted to correct the swing but he induced an oscillation in yaw. The pilot believed the airspeed was sufficient for flight, but as the aircraft lifted off it immediately stalled. The right wing tip then struck the grass to the right of the runway, causing the aircraft to rotate through 180º, before coming to rest in a gorse bush. The aircraft suffered extensive damage to its wings, tail structure, landing gear, engines and nose structure.

The pilot and the two passengers, who were wearing lap strap harnesses, suffered minor injuries but were able to exit the aircraft normally.

In a frank assessment of the accident, the pilot stated that the main cause was a series of "bad command decisions". Firstly, he admitted that he did not look at the airspeed at the time he decided to take off, believing the aircraft was at a flying speed and that taking off was a better option than running off the side of the runway into the rough verge. The pilot also admitted that he should have considered aborting the takeoff. He had not previously carried out an aborted takeoff, either when flying this aircraft or with an instructor. He also stated that his inexperience of flying taildragger aircraft from hard surfaces may have been a contributory factor.

ACCIDENT

Aircraft Type and Registration:	Taylor Monoplane, G-BDNO
No & Type of Engines:	1 Volkswagen 1600 piston engine
Year of Manufacture:	1977
Date & Time (UTC):	10 January 2009 at 1200 hrs
Location:	Bodmin Airfield, Cornwall
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - None
Injuries:	Crew - 1 (Minor) Passengers - N/A
Nature of Damage:	Engine detached and left wing damaged
Commander's Licence:	Private Pilot's Licence
Commander's Age:	66 years
Commander's Flying Experience:	246 hours (of which approximately 1 hour was on type) Last 90 days - 4 hours Last 28 days - 1 hour
Information Source:	Aircraft Accident Report Form submitted by the pilot

Synopsis

Whilst carrying out a high-speed taxi run along Runway 13 the aircraft become airborne, stalled and struck the ground in a 'left wing low' attitude. The pilot had no experience of flying taildragger aircraft and during the taxi run it may have been the wind conditions that caused the aircraft to become airborne.

History of the flight

The pilot, who had recently purchased the aircraft, was intending to carry out some taxi runs to develop an understanding of the handling of the taildragger aircraft. Prior to this 'flight' the pilot had never flown or taken instruction on how to fly a taildragger aircraft, with all his experience being on conventional nosewheel aircraft. A friend, who did have taildragger experience, was giving the pilot some guidance but, as the Taylor Monoplane is a single-seat aircraft, the friend was not able to accompany the pilot during the taxi runs.

There was no intention to fly the aircraft and the pilot initially taxied the aircraft around the manoeuvring area before then taxiing to the runway to conduct some high-speed runs. The first of these high-speed taxi runs, along Runway 13, was without incident and the pilot taxied back to the holding point of Runway 13 in preparation for a second taxi run. He lined up on Runway 13 and opened the throttle halfway with the control stick full back. The wind at this time was reported as being from 160º at 13 kt. From this point onward the pilot has no recollection of what happened up to the time he was later recovering in hospital.

A witness saw G-BDNO begin its second high-speed taxi. The aircraft then became airborne, some 20° off the runway heading and in a near vertical attitude. At about 30 feet agl the aircraft stalled and the left wing dropped. The left wing struck the ground first and the aircraft then cartwheeled; the engine and its cowlings detached at this point. The aircraft then came to rest upright, however the pilot was unconscious and rescue services had to extricate him from the cockpit due to the risk of fire from leaking fuel; fortunately there was no fire. The pilot was taken to hospital where he recovered from his injuries.

The pilot later assessed that whilst carrying out the taxi run a gust of wind may have allowed the aircraft to become airborne and his inexperience on taildragger aircraft was probably a contributory factor. He had intended to complete a few hours of ground manoeuvring to obtain a feel for the aircraft's handling and then to undertake some flying training in a two-seater Aeronca before attempting to fly G-BDNO.

ACCIDENT

Aircraft Type and Registration:	Vol Mediterrani VM-1 Esqual, PH-GCJ
No & Type of Engines:	1 Jabiru 3300 piston engine
Year of Manufacture:	2008
Date & Time (UTC):	13 January 2009 at 1254 hrs
Location:	Ludham Airfield, Norfolk
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	Main landing gear damaged
Commander's Licence:	Private Pilot's Licence
Commander's Age:	50 years
Commander's Flying Experience:	1,675 hours (of which 14 were on type) Last 90 days - 30 hours Last 28 days - 11 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

Synopsis

The pilot lost directional control of the aircraft whilst landing on Runway 25 at Ludham Airfield; it ran off the right side of the runway, about 110 m from the upwind end, into a cultivated field. The pilot was uninjured and damage was confined to the aircraft's main landing gear. Runway 25, which was described as damp at the time, is a 459 m concrete runway with a displaced threshold and a landing distance available of 420 m. The weather was fine, with a surface wind estimated at 5 kt from the west. The aircraft has a castoring nosewheel, with ground steering achieved through differential braking. The pilot thought that the main wheels had locked up whilst braking after landing fairly well into the runway, leading to the loss of control. He considered that not making an early go-around decision and a lack of recent ground handling practice were contributory factors.

BULLETIN CORRECTION

AAIB File:	**EW/C2008/06/01**
Aircraft Type and Registration:	Cessna Citation 560XL, G-OROO
Date & Time (UTC):	29 June 2008 at 1815 hrs
Location:	En route from Bournemouth, Dorset, to Biggin Hill, Kent
Information Source:	AAIB Field Investigation

AAIB Bulletin No 3/2009, page 7 refers

In the report on the incident to G-OROO, it was stated in the heading information:

> *'**Nature of damage:** Cowling and rudder'*

This should read:

> '**Nature of damage:** Cowling and **fin**'

Additionally, the synopsis states that:

> *'...the left engine upper cowling detached, damaging the leading edge of the fin and left elevator.'*

This section of the report should read:

> '..the left engine upper cowling detached, **resulting in damage to** the leading edge of the fin **and a scuff mark on the left horizontal stabiliser de-ice boot.**'

Similarly, the last line of the section titled:

> *'History of the flight'*

should read:

> '…the fin and **producing a scuff mark on the left horizontal stabiliser leading edge de-ice boot.**'

AIRCRAFT ACCIDENT REPORT No 3/2009

This report was published on 21 May 2009 and is available on the AAIB Website www.aaib.gov.uk

REPORT ON THE SERIOUS INCIDENT TO BOEING 737-3Q8, G-THOF ON APPROACH TO RUNWAY 26 BOURNEMOUTH AIRPORT, HAMPSHIRE ON 23 SEPTEMBER 2007

Registered Owner and Operator	Thomsonfly Ltd
Aircraft Type	Boeing 737-3Q8
Nationality	British
Registration	G-THOF
Place of Incident	On approach to Runway 26 at Bournemouth Airport, Hampshire
Date and Time	23 September 2007 at 2250 hrs (All times in this report are UTC)

Synopsis

The Air Accidents Investigation Branch was notified by the operator on the 5 October 2007 of an unstable approach and stall during a go-around by a Boeing 737-300 aircraft, G-THOF, at Bournemouth Airport. The event had occurred 12 days previously on the 23 September 2007.

The following Inspectors participated in the investigation:

Mr K Conradi	Investigator-in-charge
Mr A Blackie	Operations
Ms A Evans	Engineering
Mr P Wivell	Flight Data Recorders

The Boeing 737-300 was on approach to Bournemouth Airport following a routine passenger flight from Faro, Portugal. Early in the ILS approach the auto-throttle disengaged with the thrust levers in the idle thrust position. The disengagement was neither commanded nor recognised by the crew and the thrust levers remained at idle throughout the approach. Because the aircraft was fully configured for landing, the air speed decayed rapidly to a value below that appropriate for the approach. The commander took control and initiated a go-around. During the go-around the aircraft pitched up excessively; flight crew attempts to reduce the aircraft's pitch were largely ineffective. The aircraft reached a maximum pitch of 44º nose-up and the indicated airspeed reduced to 82 kt. The flight crew, however, were able to recover control of the aircraft and complete a subsequent approach and landing at Bournemouth without further incident.

Although the commander reported the event to the operator the following morning, his initial Air Safety Report (ASR) contained limited information and the seriousness of the event was not appreciated until the Quick Access Recorder (QAR) data was inspected on 4 October 2007.

G-THOF was not subjected to an engineering examination to ensure its continued airworthiness and remained in service throughout this period.

The investigation identified the following causal factors:

1. The aircraft decelerated during an instrument approach, to an airspeed significantly below the commanded speed, with the engines at idle thrust. Despite the application of full thrust, the aircraft stalled, after which the appropriate recovery actions were not followed.

2. The trimmed position of the stabiliser, combined with the selection of maximum thrust, overwhelmed the available elevator authority.

The investigation identified the following contributory factors:

1. The autothrottle warning system on the Boeing 737-300, although working as designed, did not alert the crew to the disengagement of the autothrottle system.

2. The flight crew did not recognise the disengagement of the autothrottle system and allowed the airspeed to decrease 20 kt below V_{REF} before recovery was initiated.

Three Safety Recommendations have been made.

Findings

Flight operations

1. The flight crew were properly licensed and qualified to conduct the flight. They were medically fit and there was no evidence of fatigue. Their training was in accordance with national regulations and the operator's requirements.

2. The aircraft was certified, equipped and maintained in accordance with existing regulations and approved procedures. At the time of the incident there were no recorded defects that might have contributed to the event.

3. The mass and centre of gravity of the aircraft were within the prescribed limits.

4. The flight had been routine until the approach at Bournemouth.

5. The autothrottle retarded the thrust to idle in response to crew inputs.

6. The autothrottle disengaged for undetermined reasons.

7. No significant fault could be found with the autothrottle warning or associated systems.

8. The disengagement of the autothrottle was not recognised by the crew.

9. The aircraft's Indicated Airspeed (IAS) decayed in line with crew expectations for an idle thrust approach and this constant deceleration approach masked the disengagement of the autothrottle.

10. No external factors degraded the flight crew's ability to monitor the aircraft.

11. The pilots were distracted at a critical phase of flight and did not properly monitor the airspeed.

12. The aircraft stalled and descended in a nose-up attitude and slowed to a minimum airspeed of 82 kt.

13. The thrust levers remained at full thrust for 26 seconds and N_1 exceeded the target N_1 for 31 seconds.

14. The flaps retraction did not materially affect the event.

15. The stall recovery techniques recommended in the manufacturer's Flight Crew Training Manual (FCTM) were not fully applied.

16. Forward trim was not used during the stall recovery.

17. A reduction in thrust lever position to a go-around (GA) thrust setting occurred 40 seconds after the go-around was initiated, which allowed sufficient nose-down elevator authority to control the pitch-up couple.

18. The speeds and pitch angles were outside the flight test envelope and outside the validated flight modelling envelope.

Flight procedures

1. The wording of the go-around drill in the Quick Reference Handbook (QRH) has the potential to prejudice pilots away from reducing thrust to match the required go-around thrust.

2. The 'go-around' drill and 'approach to stall' drill in the QRH do not mention trimming the aircraft.

3. The upset recovery techniques outlined in the QRH, FCTM and the manufacturer's training aid are effective and would have resulted in earlier recovery of the aircraft.

Safety management

1. The Air Safety Report (ASR) as filed by the commander did not depict the event accurately.

2. The ASR was received at the operator's offices the morning after the event but was not initially filed as an Mandatory Occurrence Report (MOR).

3. The ASR was passed to the Operational Flight Data Monitoring (OFDM) analyst on the day after the event and was reviewed that day when the OFDM analyst flagged the event for a pilot representative.

4. The flight data was not viewed by a pilot representative until 11 days after the event. This delay in reviewing the data resulted in the loss of information of value to the investigation.

5. The delay in reviewing the data allowed both the aircraft and the crew to continue operating without the incident being reviewed.

6. There was no requirement in the company OFDM agreement to de-identify the data and the data could have been reviewed on the day after the event.

7. The operator has undertaken significant changes in their OFDM and safety management system following this event.

Causal factors

The investigation identified the following causal factors:

1. The aircraft decelerated during an instrument approach, to an airspeed significantly below the commanded speed, with the engines at idle thrust. Despite the application of full thrust, the aircraft stalled, after which the appropriate recovery actions were not followed.

2. The trimmed position of the stabiliser, combined with the selection of maximum thrust, overwhelmed the available elevator authority.

Contributory factors

The investigation identified the following contributory factors:

1. The autothrottle warning system on the Boeing 737-300, although working as designed, did not alert the crew to the disengagement of the autothrottle system.

2. The flight crew did not recognise the disengagement of the autothrottle system and allowed the airspeed to decrease 20 kt below V_{REF} before recovery was initiated.

Safety Recommendations

Safety Recommendation 2009-043

It is recommended that Boeing, in conjunction with the Federal Aviation Administration, conduct a study of the efficacy of the Boeing 737-300/400/500 autothrottle warning and if necessary take steps to improve crew alerting.

Safety Recommendation 2009-044

It is recommended that The European Aviation Safety Agency review the requirements of Certification Standard 25 to ensure that the disengagement of autoflight controls including autothrottle is suitably alerted to flightcrews.

Safety Recommendation 2009-045

It is recommended that Boeing clarify the wording of the approach to stall recovery Quick Reference Handbook Non-normal Manoeuvres to ensure that pilots are aware that trimming forward may be required to enhance pitch control authority.

FORMAL AIRCRAFT ACCIDENT REPORTS
ISSUED BY THE AIR ACCIDENTS INVESTIGATION BRANCH

2008

3/2008 British Aerospace Jetstream 3202, G-BUVC
at Wick Aerodrome, Caithness, Scotland
on 3 October 2006.

Published February 2008.

4/2008 Airbus A320-214, G-BXKD
at Runway 09, Bristol Airport
on 15 November 2006.

Published February 2008.

5/2008 Boeing 737-300, OO-TND
at Nottingham East Midlands Airport
on 15 June 2006.

Published April 2008.

6/2008 Hawker Siddeley HS 748 Series 2A, G-BVOV
at Guernsey Airport, Channel Islands
on 8 March 2006.

Published August 2008.

7/2008 Aerospatiale SA365N, G-BLUN
near the North Morecambe gas platform, Morecambe Bay
on 27 December 2006.

Published October 2008.

2009

1/2009 Boeing 737-81Q, G-XLAC,
Avions de Transport Regional ATR-72-202, G-BWDA, and
Embraer EMB-145EU, G-EMBO
at Runway 27, Bristol International Airport
on 29 December 2006 and
on 3 January 2007.

Published January 2009.

2/2009 Boeing 777-222, N786UA
at London Heathrow Airport
on 26 February 2007.

Published April 2009.

3/2009 Boeing 737-3Q8, G-THOF
on approach to Runway 26
Bournemouth Airport, Hampshire
on 23 September 2007.

Published May 2009.

AAIB Reports are available on the Internet
http://www.aaib.gov.uk