BAe ATP, G-BUUP

AAIB Bulletin No: 9/98 Ref: EW/C97/8/2 Category: 1.1

Aircraft Type and Registration:	BAe ATP, G-BUUP
No & Type of Engines:	2 Pratt & Whitney PW-126 turboprop engines
Year of Manufacture:	1988
Date & Time (UTC):	3 August 1997 at 1908 hrs
Location:	Manchester Airport
Type of Flight:	Public Transport
Persons on Board:	Crew - 4 + 1 - Passengers - 62 + 3
Injuries:	Crew - None - Passengers - 2 minor
Nature of Damage:	Substantial to left main landing gear housing, engine nacelle and left wing trailing edge flaps
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	40 years
Commander's Flying Experience:	5,500 hours (of which 4,000 were on type) Last 90 days - 185 hours Last 28 days - 70 hours
First Officer's Flying Experience:	605 hours (of which 220 were on type) Last 90 days - 198 hours Last 28 days - 89 hours
Information Source:	AAIB Field Investigation

Introduction

The crew reported for duty at 1050 hrs to operate two return flights from Manchester to Belfast City and Knock in Southern Ireland. Due to an aircraft change and ground handling problems the

departure to Belfast City was delayed from 1150 hrs to 1253 hrs. The two flights to Belfast were, however, completed uneventfully and the aircraft arrived back at Manchester at 1515 hrs, in time for the scheduled 1530 hrs departure to Knock. Before departing for their third sector, the original two cabin crew were joined by an additional cabin crew member, experienced in cabin procedures but new to the company, who was to act as a supernumerary to observe the cabin procedures and assist, if required.

History of the flight

The aircraft, carrying 63 passenger and 'round trip' fuel of 2,400 kg, departed Manchester for Knock at 1600 hrs from Runway 06, on a WALLASEY 1S (WAL 1S) Standard Instrument Departure (SID), with the first officer as the pilot flying (PF). The weather was fine with a surface wind of 090°/10 kt, a few clouds at 2,500 feet and broken cloud at 5,000 feet, with a surface temperature of 18°C and a QNH of 1020 mb.

After take off, the commander selected the landing gear (L/G) 'UP' and saw the landing gear indicator lights change, as expected, from '3 Greens' to '3 Reds'. The nose and right main landing gear lights then went out, but the left main landing gear red light remained illuminated. The aircraft continued on the SID and at 2,000 feet agl the commander selected the landing gear down again. After the normal gear transit time, the nose and right main landing gears indicated 'down and locked' (Green), but the left main gear 'Red' unsafe indication remained. The commander duly informed ATC that they had a problem with the landing gear and asked for radar vectors to a suitable area to hold. The aircraft was directed to hold at 'MIRSI' (17 nm on the 065° radial from Wallasey) at FL080 in VMC (visual meteorological conditions).

The No 1 cabin attendant came to the flight deck when she heard the sound of the landing gear being selected down again. The commander explained the situation and advised her that he would keep her informed as events progressed. He then explained the situation to the passengers on the Passenger Address (PA) system. The first officer engaged the autopilot and continued to act as the pilot flying while the commander proceeded to action the Abnormal Checklist entitled 'ABNORMAL AND EMERGENCY LOWERING OF LANDING GEAR'.

At the point where the Checklist required a check of the landing gear mechanical indicators, the commander took control of the aircraft and sent the first officer into the cabin to observe the indicators. These indicators are of the 'semaphore type' and are located on the upper rear inboard side of the engine nacelles. The right main landing gear mechanical indicator indicated locked

down, but the left main gear indicator did not. The first officer then, in accordance with the Checklist, operated the main 'landing gear (L/G) emergency uplock releases' (located in the passenger cabin in line with the wing main spar) and the commander, after advising the passengers, accelerated the aircraft to 175 kt. However this and further actions, including the selection of the hydraulic landing gear changeover, had no effect on the landing gear problem.

The commander reported that, at some stage during these drills, he also noticed an 'HYDRAULIC OVERHEAT' indication. He therefore also actioned the 'HYDRAULIC OVERHEAT' Checklist and the overheat indication later extinguished.

The commander then continued with the 'EMERGENCY LANDING GEAR LOWERING WITH L/G CHANGEOVER LEVER INEFFECTIVE' Checklist. This required, amongst other actions, the simultaneous selection of all three landing gear emergency uplock releases. The nose landing gear release is located on the flight deck within reach of the first officer (only) and therefore the No 2 cabin attendant was briefed to operated the main landing gear uplock releases that were situated in the passenger cabin. Throughout this drill, the No 1 relayed messages to the No 2 from her position at the flight deck door. With no change in the landing gear condition, the commander again accelerated the aircraft to 175 kt and induced rapid pitching movements with the control column, in accordance with the Checklist procedure. After some 5 minutes, the first officer went to the rear of the cabin to check the position of the wheels visually. He reported back to the commander that the right wheels were down, but the left wheels were not visible and the left landing gear doors were closed.

The commander had, by this stage, carried out all of the emergency procedures available to him. He re-briefed the passengers and then liaised with his company operations control, advising them of his intentions. He also briefed ATC that he would remain in the MIRSI hold to burn fuel down to an amount to land at Manchester with a little over the final reserve fuel of 280 kg, sufficient to divert to Liverpool. He also declared a full Emergency.

During the extended period (3 hours) in the hold, with the first officer acting as the PF, the crew actioned the 'LANDING WITH LANDING GEAR NOT FULLY LOCKED DOWN' Checklist. The commander took control and the cabin was fully ready for the emergency landing as the aircraft departed the hold to land back at Manchester. The normal 'DESCENT' and 'APPROACH' checks were completed and at 1,000 feet on finals the commander instructed the passengers and crew to "TAKE UP FORCED LANDING POSITIONS". At 200 feet the commander announced "BRACE BRACE".

The aircraft landed on Runway 06 (3,048 metres x 46 metres) at 1904 hrs using 27° of flap and with a calculated threshold speed of 101 kt. The surface wind was 090°/12 kt. On touchdown, the first officer selected both condition levers to OFF and the hydraulic and LP cocks to SHUT. The commander managed to fly the left wing clear of the runway surface for a few seconds before the

left side of the aircraft settled onto the left engine nacelle and the trailing edge of the left wing flaps. The aircraft was kept straight by the use of right brake. A small flash fire initiated from the underside of the left engine nacelle due to the sliding contact with the runway. When the aircraft came to rest, the first officer fired both fire extinguishers and opened his sliding window. The commander, having made a PA directing the passengers to evacuate the aircraft via the right side exits, switched off both batteries. The first officer exited the aircraft through the right DV window whilst the commander entered the passenger cabin to check that all passengers and the cabin crew had evacuated.

The aircraft came to rest by link 'X', approximately half way along the runway. The emergency services, which were stationed at 'E' and 'C' intersections prior to the touchdown, were in attendance within 30 seconds. There was no further fire and the passengers and crew evacuated the aircraft successfully. Two of the passengers sustained minor injuries.

Cabin preparation and evacuation

The No 1 cabin attendant had been fully briefed by the commander on the nature of the emergency and the expected time of landing back at Manchester. She in turn briefed both the No 2 and the supernumerary cabin crew member. The supernumerary had already been given a refresher briefing by the No 1 on the doors, exits and emergency equipment prior to departure. Preparation of the cabin for the emergency landing was commenced approximately 1 hour before touchdown. Before making the emergency announcement, the No 1 moved those passengers who were seated in line with the left propeller disk to other seats and all three cabin crew then stowed all the loose hand baggage in the overhead lockers. The passenger seated in seat 8D (ie adjacent to the right overwing emergency exit) was also moved to another seat to allow the supernumerary to take that position. The passengers had time to practice adopting the 'brace' position and to have their actions checked by the cabin crew. Female passengers wearing high-heel shoes had time to remove them and to stow them either in the seat pockets or in the overhead lockers. A disabled passenger, seated in the row 3, was also asked to confirm that he could walk to the exits unaided and two 'unaccompanied minors' seated in the front cabin, near to the No 1's seat, were reassured by her and advised that she would attend to their evacuation.

At 1,000 feet on final approach the cabin crew adopted their forced landing positions. The No 1 was seated at the front of the cabin on the left side, close to the flight deck. The No 2 was seated in the rear cabin and the supernumerary was in seat 8D, next to the right overwing emergency exit. By this stage, the emergency cabin lights had been selected ON, with the main cabin lights OFF. At 200 feet on the approach the passengers and cabin crew adopted their 'brace' positions.

The No 1 reported that the touchdown was smooth with the aircraft coming to rest at a slight angle. On the instructions from the commander the cabin crew and passengers began the evacuation. The

No 1 left her seat and ushered the two unaccompanied minors towards the right overwing exit. She then returned to the front of the cabin to assist the other passengers. Moments later she was joined by the commander and together they assisted the disabled passenger out of the right overwing exit. The No 1 followed that passenger and left the aircraft. Once outside she joined the passengers who had gathered on the grass and commenced a head count. She reported that she had little co-operation from the passengers in conducting this count and that several of the passengers had started to smoke. The commander, who left the aircraft through the right overwing exit, was the last to leave the aircraft.

As the aircraft stopped the No 2, who prior to touchdown had rebriefed the passengers by the rear galley on the operation of the doors and emergency slides, opened the right rear door, inflated the slide and assisted the passengers to leave the aircraft. All of the passengers in the rear cabin had left the aircraft while other passengers were still queuing in the forward aisle to evacuate through the right overwing exit. The No 2 therefore called upon those passengers to make their way to the rear. Unfortunately, at that time there was a young girl at the front of the queue with her parents. She was reluctant to leave her parents and move to the rear. Before she did so a fireman, seeing that no more passengers were evacuating from the rear door, entered the cabin and moved forward down the aisle. With his task complete, the No 2 left the aircraft through the right rear door.

The supernumerary cabin crew member released the right overwing escape hatch and threw it clear of the aircraft immediately the commander had given the evacuate instruction. He exited and stood on the wing to assist the passengers. On several occasions he had to reach inside the aircraft in an attempt to restow the tray table in the back of the seat adjacent to, and in front of, the emergency exit since it had become dislodged and was partially blocking the exit. He eventually came face to face with the fireman who had boarded at the rear. Realising that his task was complete, he then jumped down from the wing.

Video evidence

A police helicopter, flying in the vicinity at the time of the occurrence, acted as a 'chase plane' during the final stages of the aircraft's approach. The approach and touchdown were filmed using the helicopter's gyro-stabilised camera. The film confirmed that the aircraft had made a smooth touchdown on its right main landing gear, before the nosewheel was lowered gently onto the runway. The left wing, with the left main landing gear retracted, was held clear of the runway for several seconds before the lower part of the left engine nacelle came into contact with the runway. As this occurred a short duration flash fire was evident. As the aircraft settled on the runway its track veered gently to the right before it came to rest on the runway. The arrival of the emergency services and the passenger evacuation were also filmed as the helicopter hovered overhead.

Flight recorders

The aircraft was equipped with a LORAL A100 Cockpit Voice Recorder (CVR) and a Plessey PV1584 digital Flight Data Recorder. Both recorders were replayed satisfactorily. The data recorder contained information on 24 continuously variable parameters and 6 discrete (switch position) type parameters.

The CVR was of 30 minutes duration and at the start of the recording the crew were going through the Checklist items for the emergency landing and were discussing the actions each would take once they were on the ground. The commander stated that he would handle the aircraft during the landing, and the first officer would shutdown the engines and activate the fire bottles into both engines. The commander would then switch off both batteries after making the evacuation call on the PA. The crew went through the sequence of actions several times during the descent. The cabin crew briefed the passengers on the emergency landing procedures before the aircraft started its final descent, and about 12 minutes before the landing the commander briefed the cabin crew on what they should expect during the landing and when, and from what side, they should evacuate the aircraft. A little later in the descent the commander asked the first officer to open the dump valves to depressurise the aircraft before the landing.

On the final approach, at approximately 800 feet and 125 kt, the flap was selected from 15 to 22 degrees. The aircraft then flew a smooth approach profile slowly reducing speed, and at 500 feet and 115 kt the autopilot was disengaged. Approaching 200 feet with an airspeed of 110 kt, flap 27 was selected and the PA call to take up the emergency landing positions was made to the cabin. Approaching 50 feet, a call to "brace" was made. As the aircraft entered the flare, at about 40 feet agl and 105 kt, right wing down aileron was progressively applied, and the aircraft touched down gently but positively at 96 kt, with a right wing down roll attitude of about 3.5 degrees. About 15 degrees of right wing down aileron and 6 to 10 degrees of nose up elevator were maintained, and some 3 seconds after touchdown the left wing started to drop and the engines were shutdown, with the fire bottles then discharged into both engines. As the engine driven generators came off line, 7 to 8 seconds after touchdown, the signals from a number of the parameters, including Heading, Attitude and Control Positions ceased. At this point the aircraft had started to turn slightly to the right. The data recorder continued to run for 6 to 7 seconds and the final information from the CVR was the call to "Evacuate" just before the recording ended, presumably as the batteries were switched off.

Main landing gear description

Configuration

The main landing gears each have two wheels on a common axle, and retract forward into the engine nacelles. The forward part of each landing gear bay which houses the wheels is equipped with a pair of conventional landing gear doors, hinged at their outer edges, and sequenced to open during gear transit and close again after the gear has extended fully. The aft part of each landing gear bay, which accommodates the landing gear main housing and oleo strut, is equipped with a separate pair of narrow hinged doors, actuated by rigid links connected directly to the gear.

Operation

Figures 1 through 2d illustrate the principal components and modes of operation of the main landing gear and forward door systems. Where appropriate, the outer wheel and brakes, the outer cam plate at the pintle, and non-relevant structural elements have been omitted for clarity. The hinged wheel bay doors are shown in simplified schematic form, comprising a single sectional slice through the doors at approximately the wheel axle location, with actuation by two link rods which allow the movements of the door actuating mechanism, the motion of the doors, and the proximity of the doors to the tyres to be illustrated.

Retraction and extension of the main landing gear is achieved by means of a conventional hydraulic actuating cylinder, connected to structure at its aft end and to the top of the landing gear housing at its forward end (Figure 1). When extended, the gear trails somewhat aft of the pintle but the oleo strut is vertical, ground reaction loads being transferred into the wing structure through a heavily constructed hinged reaction-link (Figure 1). When the gear is down and locked, the hinge pin at the centre of this reaction link engages the downlock hook mechanism (Figure 2a), and the bottom segment of the reaction link thus forms a vertical strut which connects the oleo casing to the wing structure, via the downlock housing.

The forward doors are moved by a pair of rigid actuating links which connect directly to the aft ends of the doors. (In the diagrams, their connection is represented by the actuating links.) Movement of the inboard ends of the door links will therefore rotate the doors about their hinge lines. The inboard ends of the actuating links are connected to the forward ends of an 'A' frame mechanism (coloured green in Figure 1), which is pivoted at its aft end against the roof of the landing gear bay. The geometry of the door links is so arranged that when the 'A' frame hinges downward about the pivot at its aft end, the door links are pushed outward, opening the doors, and vice versa. A spring pot mechanism, connected between the aft part of the 'A' frame and the roof of

the landing gear bay, applies a force at all times to rotate the 'A' frame downwards (see Figures 2a and 2b). Motion of the 'A' frame is controlled by two separate and independent mechanisms, depending on the position of the landing gear in its cycle.

The full retraction sequence is illustrated in Figures 2a through 2d. When the gear is extended (Figures 1 and 2a), a forked lever (coloured dark blue and shown clearly in Figure 2b) attached the outboard end of the pintle shaft engages a roller (coloured red) attached to the aft end the 'A' frame actuating link, which extends aft from the rear outboard end of the 'A' frame. This roller operates within the confines of a pair of slotted cam plates (coloured yellow, outer cam plate omitted for clarity). The cam plate cut-outs are shaped so as to maintain the roller in engagement with the forked end of the pintle lever whenever the landing gear is within approximately 50° of the fully extended position, and to facilitate a clean re-engagement at the appropriate point in the gear extension cycle. Movement of the 'A' frame is therefore controlled by the pintle lever whenever the gear is within approximately 50° of the fully extended position.

As the gear starts to retract, rotation of the pintle shaft forked lever draws the 'A' frame actuating rod rearward and the 'A' frame rotates downward, opening the wheel bay doors. By the time the gear has retracted through an angle of approximately 50°, the doors have reached their fully open position and the actuating rod roller disengages from the forked lever, leaving the 'A' frame in its fully down position against the end travel-stop on the spring pot mechanism (Figure 2b). The 'A' frame remains disconnected from the landing gear as retraction continues, and is held in position by the spring pot until the wheels have passed through the open doors.

Once the wheels have cleared the doors, a fork fitting bolted to the forward face of the landing gear housing (coloured orange in the Figures) engages a roller (coloured red in Figure 2b) attached to the forward end of the 'A' frame (Figure 2c). (The rearmost pair of forks on this fitting project further than the front pair, so as to guide the roller between the forks as the engagement progresses.)

Thereafter, the 'A' frame lifts with the gear and the forward doors start to close. As the gear reaches the fully retracted position (Figure 2d), the 'A' frame has been pivoted into a horizontal position, close to the roof of the bay, pulling the doors fully closed. With the gear in this position, the uplock hook engages the uplock pin mounted between the plates of the fork fitting on the leg (see Figures 2c and 2d), and a microswitch on the lock mechanism extinguishes the red 'GEAR IN TRANSIT' light on the flight deck.

Gear extension is a reversal of the above process. The uplock hook is withdrawn, and with the 'A' frame roller still engaged in the fork fitting on the forward face of the landing gear housing, the frame swings downward with the leg, opening the doors to permit passage of the wheels. As the wheels start to pass through the doors, the 'A' frame reaches the limit of its travel and disengages

from the fork fitting on the leg. The 'A' frame then remains down, holding the doors open, until the forked lever on the pintle shaft re-engages the (ready-positioned) 'A' frame actuating rod roller; thereafter, the actuating rod is driven forward, lifting the 'A' frame and closing the doors again.

Examination of the aircraft

Runway contact damage

As can be seen in Figure 2d, when the main gear is in its retracted position the top of the oleo housing is angled downward, forming a 'heel' which projects somewhat below the rest of the landing gear. On G-BUUP, the landing gear doors covering this part of the gear had worn through due to runway contact, and the protruding part of the oleo housing had been ground away, allowing the escape of oleo fluid under pressure. A brief flash fire had ensued, causing some localised sooting of the landing gear bay, but there was no heat damage. The centre-jointed part of the reaction link had also been partially ground away.

The heel of the oleo supported the weight of the aircraft which would normally be taken by the left main gear during the ground slide, and this had maintained the fuselage and wing structures clear of the ground. As a result, damage caused by contact with the runway was confined to the left wing trailing edge flap, the aft edges of which had brushed the runway. The left tailplane tip had evidently come very close to contacting the runway, but was not damaged in the accident.

Preliminary examination of the left main landing gear

The left main landing gear appeared to be at, or close to, its fully retracted position with the wheel bay doors almost fully closed. With the aircraft lifted clear of the ground, but still on the runway, the inboard wheel bay door was disconnected from its actuating link by removal of the securing nut, which is accessible from the external face of the door. The door opened readily, but the cause of the hang-up was not immediately apparent and the aircraft was therefore recovered to a hangar before any further inspections were made.

Detailed examination

With the aircraft jacked and level, it was noted that the remaining wheel bay door was jammed hard up against the tyre. However, access inside the bay was restricted and a further visual inspection yielded nothing of significance. A hydraulic jack was therefore placed under the exposed inboard tyre in readiness to support the weight of the gear, and the remaining forward door was disconnected from its operating link. As this door was allowed to open, the leg dropped perceptibly onto the supporting jack. With both forward doors open, a visual inspection revealed the following:

The roller at the forward end of the 'A' frame was not properly engaged inside the fork fitting on the forward face of the leg; instead, the roller was resting on the outside face of the forks. The enlarged inset to the left side of Figure 3 illustrates this condition. (The inset on the right side of Figure 3 shows correct engagement.)

As a direct consequence of this misengagement:

i) the 'A' frame had been driven hard up against the roof of the landing gear bay, causing minor damage to both;

ii) the landing gear had been prevented from reaching its fully retracted position, whilst the doors were pulled closed slightly prematurely;

iii) as the doors were pulled closed, they had become jammed hard against the tyres. (The door actuating links connect to the doors at their aft ends, whereas the tyre contacts occurred at the forward ends of the doors. Consequently, the jamming action of the doors against the tyres had 'sprung' the doors slightly, sufficient to accommodate the positional mis-match between the gear and the door.);

iv) the uplock had been unable to engage; this was the reason for the red 'GEAR IN TRANSIT' light on the flight deck.

Heavy black rubber deposits were evident on the inner faces of the doors, in the area where the door is recessed to accommodate the tyres. These marks were consistent with the doors having been jammed closed against the tyres while they were still spinning.

The hydraulic jack was progressively lowered, whereupon both the landing gear and the 'A' frame mechanism descended freely, with the roller on the latter running back along the outer face of the forks until it dropped off the end of the forks and the 'A' frame reached its limit of travel; the leg then dropped clear of the 'A' frame, and continued to extend. The motion of the 'A' frame and the spring pot mechanism was smooth and progressive throughout, and the limit of 'A' frame travel was reached without any intervention.

Once the leg had descended to its lowest position, it was manually rocked rearward until the downlock engaged, giving a green 'safe' indication on the flight deck. This action was free of restriction and the effort required to move the leg manually into downlock engagement was judged normal.

The hydraulic system was pressurised and the leg retracted slowly, under power, whilst the 'A' frame roller engagement with the fork fitting was monitored visually. The roller engaged the forks cleanly and retraction continued normally, culminating in a normal engagement of the uplock; this extinguished the red 'GEAR IN TRANSIT' light on the flight deck. Further cycling of the landing gear at a range of different rates, including a normal retraction, failed to reveal any abnormality.

Using the hydraulic jack to manoeuvre the gear, the position of the 'A' frame was adjusted manually to establish the lowest position of the frame which would cause the roller to miss the forks. It was established that misengagement would occur if the 'A' frame was lifted by even a small amount from its fully down position, equivalent to approximately 8 mm extension of the spring pot. Figure 4a shows the mechanism in this condition, with the roller just resting on the outer face of the forks ('X'); 'Y' points to the 8 mm displacement the spring pot. Figure 4b shows the point of fork engagement with the 'A' frame roller at its correct (fully lowered) position.

Careful checks were made for any evidence of binding or wear in the 'A' frame mechanism and its related components including the actuating link rod, its roller, and the pair of cam plates at the pintle but all proved negative; movement of the door actuating mechanism was smooth at all times, with no evidence of sticking or jamming. (A small degree of misalignment was noted at the spring pot mounting brackets which attached to the roof of the bay, and the spacing between the brackets was approximately 1 mm wider than the corresponding item on the right landing gear. However, these minor defects did not result in any discernible stiffness or restriction in the spring pot.) The door links were correctly installed and the anti-rotation fittings, which control the orientation of the eye-end fittings, were correctly positioned; if incorrectly positioned, geometric locking and/or fracture of the link rods would have been possible. The rigging of the pintle cam plate and the roller on the 'A' frame actuating rod provided adequate 'hand-off' between the two operating modes, and there was no scope for rigging mismatches to have caused the 'A' frame to jam out of position. The cam plate profiles and the actuating rod roller were checked carefully for wear, and in particular for any evidence of notching or damage to the working faces of the roller tracks which could have

caused the roller to bind in the tracks. No significant damage or wear was found; neither was it possible to bind the roller in its track by canting it in the cam slots.

The rate characteristic of the spring pot was compared with that from the right landing gear, and found to be identical. Examination of the spring pot in situ revealed that the rivets securing the (bottom) eye-end fitting to the inner sleeve of the mechanism were loose and the rivet holes in the sleeve were severely elongated, creating a small amount of axial float in the end fitting. This would have increased, very slightly, the effective length of the spring pot when fully extended, which in turn would have affected slightly the position of the 'A' frame whilst it was being maintained at its lowered position by the spring pot. However, the resulting mis-positioning of the 'A' frame was not in the critical direction, and was demonstrated to have had no adverse effect on its engagement with the fork fitting; nor was it possible for the spring to become jammed on the loosened rivet heads.

Significant amounts of grease and dirt were present on the spring pot assembly raising the possibility of grit, thrown up from the wheels, having become stuck to the grease and subsequently causing the inner sleeve to bind in the yoke fitting, due to grit particles becoming drawn into the sliding parts of the unit as the gear was cycled. The spring pot assembly was therefore enclosed in a bag to retain all foreign material and to avoid further contamination, removed from the aircraft, and taken to Farnborough for detailed investigation.

Detailed examination of the spring pot assembly

Dismantling of the unit was undertaken carefully so as to retain the grease and any debris which it contained. Figure 5a shows the spring pot components before degreasing. Figure 5b shows the rivet hole damage to the inner sleeve connection of its end fitting.

The components were degreased and the solvent filtered and dried off, leaving behind the solids originally held in the grease. This material was found mainly to comprise a graphite-like agglomerate, within which there were a significant number of grit particles of sizes comparible with the sliding clearance between the spring pot sleeve and the yoke. Microscopic examination of the sleeve and the bore of the yoke revealed numerous axial score/wear marks. Several scores were significantly deeper than the majority, and one appeared relatively fresh; this score stopped a short distance into the bore, and was consistent with the entrapment of a grit particle; see Figures 6a and 6b. Whilst it was not possible to identify the specific cause of this score mark, its dimensions were consistent with the sizes of the grit particles recovered from the grease. Figure 6c show examples of these grit particles under high magnification.

Cause of the landing gear malfunction

The failure to extend

It was clear that during retraction of the landing gear after take off the 'A' frame roller had failed to correctly engage the fork fitting on the forward face of the gear; instead of entering the forks correctly, the 'A' frame roller had rode upon the forward face of the forks. This had caused a slight mis-match in the phasing of the doors with the gear, with the 'A' frame starting to lift and pull the doors closed prematurely, though not sufficiently early to cause the wheels to foul the doors as they were entering the bay. However, as the gear approached the fully retracted position, the 'A' frame contacted the roof of the bay, preventing the gear from reaching the fully retracted position, whilst at the same time the doors were closing slightly earlier than normal. As a consequence, the landing gear doors were pulled hard up against the still rotating tyres, jamming firmly against them as the 'A' frame was driven against the roof of the bay. Because the gear was unable to quite reach its correct position in the bay, the uplock hook was unable to engage and the red gear in transit light on the flight remained on, alerting the crew to a problem.

The landing gear doors are recessed on their inside faces to accommodate the tyres. Contact between the tyres and the doors therefore occurred mainly on the tread region of the tyres, rather than on the sidewalls (see Figure 7a), as evidenced by the black rubber marks on the inside face of the door (see Figure 7b). As a consequence, with the doors pulled up hard and the door actuating links effectively strapping them to the tyres, high friction forces were developed between the tyres and the inner surfaces of the doors. Furthermore, because the overtravel of the 'A' frame would have been accommodated by springing of the doors and the compliance in the tyres, a substantial pre-load would have been maintained thereafter, binding the whole assembly together.

The geometry of the door mechanism was such that, for the gear to be able to extend subsequently, a lateral sliding motion would have been necessary between the tyres and door inner surfaces. However, because of the pre-load, due to the combination of sprung doors and the self-reacting geometry of the mechanism overall, the tyre contact forces would have been very high, and the resulting friction forces large, almost certainly sufficient to resist the lateral sliding motion required between the tyres and the doors to permit the gear to start to extend. (The effective friction is likely to have been further enhanced by the partial melting of rubber as the doors jammed up against the still spinning tyres during the retraction.) The hydraulic actuator forces attempting to lower the gear would have increased the normal force developed between the tyres and the doors, increasing still further the friction force resisting the sliding motion necessary to free the jam. It is apparent that this effect, together with the relatively poor mechanical advantage of the actuator, prevented the gear from extending. Quite clearly, all attempts to free-fall the gear would have been ineffective under these conditions.

Cause of the 'A' frame mis-engagement

Consideration was given as to whether aerodynamically induced side loads acting on the doors, for example due to sideslip, could have back-driven the door links and held the 'A' frame out of position during retraction of the gear on take off. However, the geometry of the 'A' frame and the door links is such that when the 'A' frame is in its lowered position, on the spring stop, the door linkage is geometrically over-centred. Consequently, side loads on the doors would have tended mainly to drive the 'A' frame sideways, with a very small rotational force on the 'A' frame tending to hold the frame down onto the spring-stop, rather than lifting it out of position.

The effects of inertia were also considered, but the combined spring and gravitational forces acting on the 'A' frame would have been such that inertial forces almost certainly would not have been capable of lifting the frame out of position, and certainly not of maintaining it there.

No mechanism could be found whereby the loose rivets in the spring pot end-fitting could have caused any jamming or binding of the mechanism.

On the available evidence, entrapment of a particle of grit into the sliding parts of the spring pot offered the only plausible explanation for the failure of the 'A' frame to engage the fork fitting correctly during gear retraction. It appeared most likely that a particle of grit (adhering to the grease on the unit) was drawn between the sleeve and the bore of the yoke as the gear was extended for landing, resulting in the spring pot binding up and preventing the unit from extending the final 8 mm (or more) onto its stop, and leaving the 'A' frame slightly out of position. During the subsequent gear retraction, the 'A' frame missed the fork fitting, its roller riding instead on the forward face of the forks. As the 'A' frame was then lifted by the continuing retraction of the gear, the spring pot was compressed again and the reversed sliding action drew the grit particle clear, leaving no direct evidence of its earlier presence.

Safety action relating to the landing gear

The aircraft manufacturer was made aware of the investigation findings, and airworthiness action initiated, at an early stage in the investigation. To date, three Service Bulletins have been issued, addressing issues affecting the 'A' frame spring pot mechanism. It is considered that these actions adequately address the technical issues raised during this investigation.

The relevant Service Bulletins are summarised below:

Mandatory Service Bulletin 2-84, issued 20 August 1997, required a change to the lubrication and inspection of the door operating mechanism, and re-lubrication of the 'A' Frame spring pot mechanism. Compliance was required within 250 hrs, with repeated inspection/lubrication at 1600 hr intervals. Revision 1 of this Service Bulletin, issued 26 September 1997, increased the time for compliance to 300 hrs.

Alert Mandatory Service Bulletin 32-85, issued 26 January 1998, required inspection for loose rivets joining the end fitting to the sleeve of the spring pot assembly, and replacement if found loose. The time for compliance was 300 hrs, with repeat inspections at 1500 hr intervals.

Service Bulletin 32-87, Mod 10447A, issued 29 January 1998, introduced a modified spring pot in which the end fitting and sleeve were manufactured as a one piece machined assembly. Embodiment of the modification provides terminating action for Mandatory Service Bulletin 32-85.

Operational factors

Communications issues

At 1625 hrs the aircraft commander informed ATC that he had a problem with the landing gear and at the appropriate time would be returning to Manchester. At 1805 hrs the commander reported that he estimated landing at 1900 hrs. ATC informed the London Air Traffic Control Centre (LATCC), the local handling agents and adjacent airfields, that Manchester would probably be closed at 1900 hrs and to expect numerous diversions. At 1820 hrs the Airport Fire Service (AFS) was informed by ATC of the emergency with the new phrase 'Aircraft Accident Imminent'. However the emergency landing should have been given the designation of 'Aircraft Accident' under the policies and procedures in force at Manchester. The term 'Aircraft Accident' is instigated when an aircraft accident occurs, or ATC has reason to believe that an accident is inevitable, on or in the vicinity of the Airport. However the aircraft was at least 30 minutes or more away from landing and, although ATC accepted that an aircraft accident was inevitable, they felt that use of the term 'Aircraft Accident' to inform external agencies would have resulted in the inevitable questions of 'when' and 'where', which could not have been answered at that time. ATC therefore, in consultation with the AFS, agreed to use the new term 'Aircraft Accident Imminent'. Nevertheless, the response from all the emergency services was timely and of the correct level to ensure that full emergency cover was provided at the time of the landing.

After the accident the new terminology of 'Aircraft Accident Imminent' was formally introduced into the levels of response by the emergency services, bringing Manchester in line with BAA airport procedures.

Aircraft Operations Manual - Emergency and Abnormal Checklist

The initial problem that was presented to the crew was that the landing gear failed to lock up after an UP selection. The only entry in the 'Emergency and Abnormal Checklist' that seemed suitable to deal with this problem was a check entitled 'UNABLE TO RAISE LANDING GEAR' (Card 36). However this was not appropriate to the situation, since it dealt mainly with a problem associated with the landing gear selector lever which, in this case, had operated correctly. Only after the commander had selected the landing gear down, with the associated main gear leg unsafe indication, was it appropriate for him to enter the Checklist on the 'Abnormal and Emergency Lowering of Landing Gear' page (Card 34). This procedure was presented to the crew as a list of actions interspersed with 'Yes/No' decision flow lines. The procedures below each flow line were presented as a list separated from adjacent non-applicable lists by line spaces alone. Notes relating to points within some procedures were positioned at the foot of the page requiring the reader to interrupt his reading of a list, in order to read a note, and then to return to the next procedure in the list of actions. The type font size used to present the procedures ranged from 2 mm to 1 mm in height. The copy of the aircraft 'Emergency and Abnormal Checklist' retained on the flight deck and available to the flight crew was bound in a red plastic cover that was split and detached at the rear. The pages, which were of black print on yellow card, were housed in plastic sleeves. The print from many of the yellow cards had become imprinted on the inside of the plastic sleeves, giving an 'out-of-focus' appearance which made the print difficult to read. The crew therefore had to remove individual cards from the sleeves in order to read the procedures. The Checklist plastic sleeves were also welded together at the spine, rendering the pages incapable of being folded back on themselves or being folded flat without difficulty.

Operational safety actions

The Operator

After the accident, the operator examined the serviceability of the drop-down seat table adjacent to the right overwing emergency exit. One hinge of the seat tray in the back of seat 7D (forward of the right wing overwing exit) was found to be unserviceable. The operator subsequently issued a General Fleet Instruction (No 97/14) stating that, with immediate effect, any defect in the retaining efficiency of the catches which secure the drop-down tables at overwing exit seat rows must be rectified, or the defective table(s) removed before further flight. Company personnel were also made aware that the retaining efficiency of such catches might be adversely affected by the serviceability of the table hinges. Company engineers were notified and cabin crew were asked to include the serviceability of such drop-down tables in their 'first-flight-of-the-day' checks.

The Manufacturer

After the accident, British Aerospace (Regional Aircraft) Ltd examined the content of the Emergency Checklists relating to 'LANDING WITH LANDING GEAR NOT FULLY LOCKED DOWN' (Card 35) and 'UNABLE TO RAISE LANDING GEAR' (Card 36). With the agreement of the operator, the manufacturer instigated amendment action on the 'Card 35' Checklist so that if one, or two, of the three landing gears failed to lock down the aircraft was to be landed on the remaining landing gear leg and not with the gear retracted, as previously suggested for a double landing gear leg failure. Card 36 was also amended to include a drill to address the question 'ARE ALL L/G LEGS UP AND LOCKED?' after the L/G selector has been moved to the UP position.

In September 1997, the CAA had published Civil Aviation Publication (CAP) 676, entitled 'Guidelines for the Design and Presentation of Emergency and Abnormal Checklists'. These guidelines, which were written mainly for public transport operations usually involving dual/multi-crew, addressed only the way in which the procedures should be presented and not the content of the procedures themselves.

Safety Recommendation

98-53 It is recommended that British Aerospace (Regional Aircraft) Ltd review the content and presentation of the ATP Emergency and Abnormal Checklist with a view to revising this Checklist in accordance with the guidelines published in CAP 676.