AAIB Bulletin No: 9/94 **Ref: EW/C93/11/6** **Category: 1.1**

Aircraft Type and Registration:	Shorts SD3-30, G-ZAPC
No & Type of Engines:	2 Pratt and Whitney PT6A-45R turboprop engines
Year of Manufacture:	1978
Date & Time (UTC):	24 November 1993 at 0240 hrs
Location:	Norwich Airport, Norfolk
Type of Flight:	Public Transport
Persons on Board:	Crew - 3 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	Damage to landing gear housings and underside of fuselage
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	40 years
Commander's Flying Experience:	4,900 hours (of which 800 were on type) Last 90 days - 136 hours Last 28 days - 36 hours
Information Source:	AAIB Field Investigation

History of flight

The aircraft, callsign ZAP 306A, departed East Midlands Airport at about 2345 hrs for a flight to Norwich Airport. On rotation, both 'HYD L' and 'HYD R' central warning panel (CWP) captions illuminated briefly and then went out. The landing gear was left extended until a check of the hydraulic services panel had been made. However, indications were normal and so the landing gear was retracted and the flight continued.

About 15 minutes later, when the aircraft was in the cruise, the 'HYD L' CWP caption again illuminated. The hydraulic pressure was normal and the contents gauge indicated halfway between the amber sector and the white full mark; in accordance with the emergency checklist, the left pump inlet valve was selected 'SHUT'.

At 0003 hrs the aircraft, which was then 58 nm from the airfield at FL55, called Norwich Approach and passed an ETA of 0022 hrs. The aircraft was cleared to 3,000 feet for an ILS approach to Runway 27. At some stage, in order to minimise damage, the left pump inlet valve was selected to 'OPEN' to lubricate the hydraulic pump; the 'HYD L' CWP caption went out. At 0029 hrs, the aircraft was established on the localiser and, in anticipation of a possible problem, flap 8° and landing gear were selected early. When landing gear was selected down, both 'HYD L' and 'HYD R' CWP captions illuminated. The crew noted the following:

a) The nose landing gear indicator was red
b) The right main gear indicator was red
c) The left main gear indicator was not illuminated
d) The flap indicator read 0°
e) The main system hydraulic pressure gauge read zero
f) The hydraulic contents gauge read just below full

The approach controller was informed that there was a problem with the landing gear and that the missed approach procedure would be carried out. The aircraft was cleared to 2,000 feet and the missed approach was initiated at 0033 hrs.

The emergency checklist required that, if both 'HYD L' and 'HYD R' CWP captions were on, and there was a low reading on the main system pressure with contents normal, then both pump inlet valves should be selected to 'SHUT' and the emergency systems should be used. The landing normal gear selector was left in the 'DOWN' position and 'LANDING GEAR DOWN EMERGENCY' lever was pulled. This action produced no change in the landing gear indications, but the 'EMERGENCY LANDING GEAR' accumulator pressure gauge showed an immediate reduction from 3,000 psi to 1,200 psi, the discharged state pressure. The hydraulic contents indication remained at just below full.

At 0053 hrs, the controller was asked if there were any airfields available with a 'foam carpet' facility. He replied that he did not think that the facility still existed. At 0100 hrs, the aircraft flew past the terminal area and observers confirmed that the nose landing gear was partially extended, but the main gear was retracted. The aircraft again entered the holding pattern at 3,000 feet, in order to reduce the fuel load, and to make further attempts to resolve the problem, in addition to planning the approach. Not being entirely certain of the landing gear position and its effect on the aircraft's performance, the commander decided to carry out a low speed handling check to establish a safe approach speed.

At 0122 hrs, the controller confirmed that there were no airfields available with a foam carpet facility and so the commander elected to make the landing at Norwich Airport. All loose articles were removed from the flight deck and stowed under the cargo net. When the crash axe was checked, it was found that the belt and buckle stowage arrangement was extremely tight and that the axe could not easily be removed. It was therefore slackened in preparation for the landing. The third crew member was briefed on the emergency and occupied a seat at the rear of the aircraft.

At 0210 hrs, the aircraft passed an expected approach time of 0240 hrs. However, at 0226 hrs the controller passed the information that shallow fog had started to form. The fuel load had reduced to about 300 lb and the aircraft started the outbound leg of the approach at 0231 hrs, with the commander handling. The aircraft established on the localiser at 0234 hrs and the first officer informed ATC that the third crew member was seated at the rear of the cabin. Both pilots had locked their seat harnesses for the approach and landing.

The approach was carried out without incident and the aircraft was held off the runway for as long as possible, the commander's intention being to touchdown on the main gear housings at minimum ground speed and rate of descent, in a nose-high attitude. After a period when the aircraft floated with slow deceleration, just prior to touchdown the first officer selected both fuel levers to 'SHUT OFF'. Touchdown, at 0240 hrs, was on the rear of the main landing gear housings. The rear fuselage also touched, and there was intense airframe vibration. Directional control was better than expected and so the commander decided to hold the nose gear off for as long as possible; when it eventually touched, directional control remained adequate. The aircraft did not decelerate as quickly as expected however and, as it appeared that the engines were still running, he asked the first officer to select reverse thrust. The first officer was unable to depress the reverse gate and retard the throttles with her left hand and, with her seat harness locked, she could not use her right hand. Shortly afterwards, the commander called for the engine low pressure (LP) valves to be shut, but the first officer was unable to move the levers. It was intended that the first officer should select the electrical master switch to 'OFF' shortly before the aircraft came to a halt, however, with her harness locked she was unable to reach the switch.

The aircraft came to a halt about 200 metres before the end of the runway and the occupants vacated the aircraft without injury. The airport and local authority rescue services were immediately on the scene. The right engine was found to be still running and so the commander returned to the flight deck and completed the shutdown drills.

Meteorology

A meteorological observation at that time of the accident recorded the following:

Surface wind	240°/03 kt
Visibility	6,000 metres
Temperature/dewpoint	-4°C/-5°C

Rescue services

The airport fire service was at a minimum manning level, however there was sufficient notice of the event for the local authority fire service to be in attendance. The appliances had positioned off the 09 end of the runway and, having been told by ATC that the aircraft had landed, they entered the runway in the belief that it had come to a halt before it reached their position. Unfortunately this was not the case, and they had to leave the runway again to clear the aircraft's path.

Standard operating procedures had not been complied with and the vehicles had entered the active runway without ATC permission. The appropriate procedures have been revised to reduce the chance of a similar occurrence in the future.

Flight deck ergonomic assessment

The positions of the cockpit controls were checked with a member of the AAIB staff, of similar build to the first officer, occupying the right seat of G-ZAPC. With the seat in the fully raised position, the harness locked, and the left hand placed on the power levers in the normal manner, the subject could lift the reverse gate. However, the movement required to fully release the gate and to move the throttles aft proved impossible.

Both LP levers, situated on the overhead panel, were within reach and a firm grip could be made with the fingers wrapped around the levers. However, the reach was such that the arm was fully extended when gripping the left lever, and almost so when gripping the right lever. With the locked seat harness preventing upper torso movement, the force required to move the lever to the 'SHUT' position has to be applied in a rearwards direction, perpendicular to the shoulder line. Physically, it would be extremely difficult for the average person to apply any great force in this direction. The difficulty would have been increased by the presence of 'tell-tale' wire locking of the LP levers into the 'OPEN' position, introduced in 1971 to prevent inadvertent closure of the LP valve whilst making fuel

crossfeed selector changes. The breaking strength of the tell-tale wire holding each lever in the 'OPEN' position is of the order of 25 to 35 lb force, to which must be added the normal resistance to movement due to control cable circuit stiffness.

The distance from the subject's shoulder to the electrical master switch was 71 cm; with the left arm fully extended the tips of the fingers were about 6 cm short of the switch and therefore it could not be operated.

When the seat was any lower than the fully raised position the situation was aggravated and it proved even more difficult to carry out any of these operations. This assessment was made in a parked aircraft with the subject under no pressure; the situation in which the first officer was required to carry out the operations would have made it even more difficult to achieve success.

The CAA has been made aware of the above aspects and consideration is being given to what action should be taken to identify and alleviate such ergonomic problems.

Preliminary examination of the aircraft

The aircraft was lifted off its underside and towed to a position clear of the main runway, where it was subsequently examined. All three landing gears were fully up and locked, and the nose gear doors were closed. (On this particular type of aircraft, landing gears in a partially extended condition will tend to be driven into the fully up and locked position as the aircraft touches down).

External examination of the visible parts of the landing gear revealed large quantities of hydraulic fluid around the left main gear. This was traced to a fracture on the body of the EMERGENCY/NORMAL shuttle valve on the 'down' side of the hydraulic retract actuator. The fracture comprised a 360° circumferential crack around the cylindrical body of the valve chamber which had allowed the normal end of the valve, with flexible hydraulic hose and connector fittings still attached, to separate from the main part of the valve with consequent loss of hydraulic fluid whilst the landing gear was selected down. The valve spool was hanging partially out of the fractured valve chamber allowing fluid from the emergency end of the valve to pass the spool and dump overboard, thus rendering the emergency lowering system inoperable.

It was noted that the flexible hydraulic line connected to the emergency end of the valve was stretched tightly across an adjoining rigid hydraulic pipe, placing a bending load on the body of the valve at the emergency end. However, this condition did not appear to be connected in any way with the failure of the valve at the normal end.

The hydraulic panel in the cockpit was checked with electrical power on. The reservoir contents gauge read off-scale, beyond the 'full' end of its range. The emergency landing gear reservoir pressure was 1,500 psi (ie fluid discharged; gas charge pressure only) but the emergency brake accumulator was still fully charged and reading 3,000 psi. The flap accumulator was checked using the accumulator pressure gauge located in the left main landing gear sponson, and was found to be discharged.

The flap selector lever was set at 15°, but the flap surfaces were fully up. The landing gear down and emergency gear selectors were both selected to gear down. Both engine emergency LP cocks were selected to shut, and the witness wire on each LP shut-off lever was broken.

Hydraulic system

The right main and nose landing gears were manually extended using an hydraulic hand pump to separately pressurise the unlock/extend port of each landing gear retraction actuator, thus unlocking the up-locks which are within the actuators. The legs were then allowed to drop under gravity and manually eased into the locked-down condition. No particular resistance to locking into the down position was noted, other than the friction inherent in the lock tongue.

The fractured shuttle valve on the left main landing gear prevented connection of the hand pump to that actuator. The shuttle valve from the right main gear was therefore removed and substituted for the damaged valve on the left main gear, to allow connection of the hand pump to the actuator ram. With the valve from the right main gear fitted, the left main gear was unlocked, allowed to free fall, and manually locked down without difficulty.

Whilst removing the shuttle valve from the right main gear, considerable difficulty was experienced in unscrewing the valve retaining bolts and undoing the hydraulic connections to the valve because of corrosion between the steel bolts and the aluminium valve body. The nuts securing the flexible hoses to the valve connectors were also extremely difficult to move, also due to corrosion between the steel nut and the aluminium connector adapter.

With the landing gears down and locked, the hydraulic connections to the landing gears were blanked off and the aircraft towed to a suitable part of the airfield in preparation for functional checks of the hydraulics system using the engine driven pumps.

Functional test of hydraulics system

Prior to replenishment of the hydraulic reservoir, consideration was given to possible reasons for the excessive contents indication on the hydraulic reservoir contents gauge. It was established that the reservoir piston position is transmitted mechanically to an electrical transducer attached to the head of the reservoir via a cable and spring-loaded drum system. Given this arrangement, it was considered that the most likely explanation for the over-full contents indication was that a rapid depletion of the reservoir, together with possible sticking of the cable drum spindle, had allowed the cable to become tangled, or mis-registered, on the cable drum. On this basis, it appeared likely that during replenishment of the system with fluid, the cable would unwind from the drum until it reached a stage where normal registration between cable and drum was restored and the system would revert to its correct datum. Progressive replenishment of the system whilst monitoring the hydraulics panel contents gauge (with electrical power on) showed the gauge starting to move in a positive (increasingly over-full) direction initially, before suddenly flicking back to a low contents reading consistent with the actual contents of the reservoir. Thereafter, as replenishment continued, the gauge continued to read correctly.

With the system fully replenished, the right engine was started. All indications during the start were normal and the main hydraulic system pressure rose to its correct value of 3,000 psi, with the emergency landing gear accumulator, emergency brake accumulator and flaps accumulator pressures reading 3,000 psi.

With only the right engine running, the right hydraulic pump inlet was closed. Initially, the system pressure remained at around 3,000 psi, thereafter slowly decaying until the 'HYD R' caption illuminated at approximately 1,800 psi main system pressure. The left engine was then started and the hydraulic system pressurised with the left hydraulic pump, the right hydraulic pump being left in the off condition. The system pressure built up to 3,000 psi normally, after which switching off the left hydraulic pump produced a similar response to that obtained for the right pump, with the 'HYD L' warning caption illuminating at about 1,800 psi.

Both pumps were switched on then, with the main system showing 3,000 psi, both pumps were switched off again. After a slight delay, the main system pressure started to fall and as the pressure decayed through about 1,800 psi both HYD captions illuminated, the 'HYD L' caption illuminating slightly ahead of the 'HYD R' caption.

Detailed examination of the failed hydraulic shuttle valve

The aluminium alloy valve body (which was 82 mm long by 26 mm in diameter) had fractured approximately 10 mm from one end, at a location coincident with the last turn of an internal thread accommodating the normal hydraulic pipe connector fitting. Evidence was found of fatigue crack growth through the thickness of the body from multiple origins in the root of the thread. These fatigue cracks extended approximately 80% around the circumference of the fracture, with complete crack penetration of the material having occurred over approximately 50% of the circumference.

The potential for high stresses to be induced at the root of the thread by 'bottoming-out' of the pipe connector male thread was considered. However, examination of the male thread length in relation to the valve body thread recess suggested that the length of the female thread was adequate to prevent bottoming out, and there was no evidence of contact at the bottom end of the thread. This possibility was therefore discounted.

Slight staining of the inner surface of the valve body was evident in the area of the fatigue origins and examination of this area under high magnification revealed numerous corrosion pits, from which fatigue growth marks could be seen emanating. No such staining or corrosion pits were evident at the emergency end of the valve body; neither was there any indication of fatigue cracking in the roots of the thread, or at any other location at that end of the valve.

Metallographic examination of a section cut from the fatigue crack origin region showed the presence of numerous intergranular stress corrosion-type cracks, together with evidence of sub-surface intergranular corrosion attack. Material composition and hardness tests produced satisfactory results.

Based on crack growth measurements using an optical microscope, it was estimated that the fatigue cracks had grown over a total of approximately 1,750 load cycles; the loading mechanism almost certainly having been the pressurisation of the valve body during each gear down selection, ie one load cycle per flight. At the time of the accident the aircraft had accumulated a total of 18,617 landings, the shuttle valve having been fitted to the aircraft throughout that time.

Possible explanation for the sequence of events

The first indication of abnormality was the brief flash of both HYD captions during rotation. This suggested that the valve body had fractured, partially at least, at some point during the takeoff and the consequent loss of fluid from the landing gear down circuit was sufficient to produce a transient pressure drop below the warning caption threshold pressure (approximately 1,800 psi). However, it

would appear that there was still sufficient fluid being supplied to the pumps to prevent a permanent drop in pressure below the warning caption threshold. When landing gear 'UP' was selected, the affected damaged part of the circuit would have been isolated by the landing gear selector valve and, once established in the cruise with flaps retracted, there would have been no further demands on the hydraulics system.

Initially, it would appear that there was sufficient fluid in the reservoir to prevent the pumps from sucking air for long enough to cause a system pressure fall to below about 1,800 psi, ie the pressure warning threshold. After about 15 minutes, one or both pumps appears briefly to have drawn sufficient air to cause the system pressure to fall just enough to trigger the 'HYD L' caption, but not the 'HYD R' caption (which was found, on test, to have a slightly lower threshold setting than the left caption). However, the fact that the 'HYD R' caption remained extinguished after the left pump had been selected off, and both captions remained unlit after the left pump was later reselected, suggests that the loss of fluid to the pump inlets which triggered the 'HYD L' caption was probably short lived.

When the landing gear was selected down, fluid would again have been directed to the damaged part of the hydraulic circuit and would have been lost overboard through the fractured shuttle valve, the marginal reservoir contents at this stage resulting in an immediate loss of system pressure and both 'HYD L' and 'HYD R' captions illuminating. The initial pressure pulse, upon selection of gear down, was apparently sufficient to break the up-locks on the right and nose gears, allowing these to free fall, but their momentum was evidently not sufficient to carry them fully down and into the locked positions.

Because the fracture in the valve body was at a common point in the normal and emergency gear extend circuits, the subsequent attempt to extend the gear using the emergency accumulator merely resulted in the emergency fluid being also dumped overboard.

LP Shut-off valve locking wire

The requirement for wire locking of the LP Shut-off valve levers was introduced by Service Bulletin SD330-28-35, which specifies the type of wire to be used, together with the crimped end-terminations which allow attachment of the restraining wire to the lever quadrant and lever arm respectively.

A sample of the wire specified in the Service Bulletin was obtained for testing, together with two restraining wires made up as specified in the Bulletin. The results indicated that the breaking force of the wire alone was of the order of 31 pounds force, whereas the restraining wire assembly, comprising the length of wire with crimped end fittings attached, broke under an applied load of approximately 22 pounds force.

The aircraft manufacturer has stated that the load required to break the wire is 9 pounds force, equivalent to 5 pounds force applied at the lever, with an estimated 12 pounds force at the lever being required to both break the wire and overcome the operating cable stiffness. Factoring these figures to take account of the measured wire breaking strain of 31 pounds implied that a force of the order of 19 pounds would actually be required at the lever in order to break the wire locking and to allow the lever to start moving back towards the shut-off position.

Safety Recommendation

94-21 It is recommended that the aircraft manufacturer and the CAA review the suitability of the wire locking arrangements specified in Service Bulletin SD330-28-35 with a view to ensuring that aircrew are able to select the engine LP fuel valves to the shut-off position during an emergency without the need to apply excessive force, having due regard to the problems of restricted access to the levers.