Avro 146-RJ100, G-BZAY

AAIB Bulletin No:	**1/2003 Ref: EW/C2002/05/02**	**Category: 1.1**
Aircraft Type and Registration:	Avro 146-RJ100, G-BZAY	
No & Type of Engines:	4 Allied Signal LF-507-1F turbofan engines	
Year of Manufacture:	2000	
Date & Time (UTC):	8 May 2002 at 1321 hrs	
Location:	Gatwick Airport	
Type of Flight:	Public Transport	
Persons on Board:	Crew - 6	Passengers - 40
Injuries:	Crew - None	Passengers - None
Nature of Damage:	Burst right main landing gear tyre with associated damage to inboard flap, landing gear fairings, sensor wiring, fuselage and wheel well.	
Commander's Licence:	Airline Transport Pilots Licence	
Commander's Age:	26 years	
Commander's Flying Experience:	4,154 hours (of which 1,738 were on type) Last 90 days - 156 hours Last 28 days - 36 hours	
Information Source:	AAIB Field Investigation	

Synopsis

The aircraft was carrying out a scheduled flight from Gatwick Airport to Paris Charles de Gaulle Airport when a main landing gear tyre burst during the take-off roll. Disintegration of the tyre damaged adjacent areas including sensor electrical wiring, which in turn led to secondary failure indications.

History of the flight

Following a normal pushback and engine start from Stand 52R, the aircraft was taxied via taxiways L and Q for Runway 08R. The aircraft entered the runway through holding point J1 and having been cleared to depart on a Seaford 8P SID, the aircraft was cleared for take off as it entered the runway. All checks having been completed, the aircraft commander who was the handling pilot, commenced a rolling take off with a surface wind reported by ATC of 030°/10 kt gusting 20 kt. During the take-off roll, the co-pilot made the standard verbal announcements including V1 at 115 kt and VR at 119 kt. During the latter stages of the take-off roll, the two flight attendants seated at the rear right of the passenger cabin noticed that the roll was noisier than normal and that it was

accompanied by a high frequency vibration. These abnormalities were not noticed by the two flight attendants seated at the front left of the passenger cabin or by the flight deck crew. However, as the commander rotated the aircraft, there was a marked shimmy which could be heard as a vibration shaking the aircraft galley.

A positive rate of climb was established and the commander called for the landing gear to be selected up. As the co-pilot made the selection, an ANTI SKID cautionary caption illuminated on the Master Warning Panel (MWP). The co-pilot also informed the commander that the right main landing gear in transit light was still illuminated showing that the retraction cycle was not complete. The commander elected to follow the SID to the cleared altitude of 6,000 feet and then review the warnings. Airspeed was limited to 190 kt with the minimum safe speed for the configuration of 179 kt. Flap retraction was carried out in accordance with the standard operating procedures and the aircraft levelled at 6,000 feet using the autopilot with altitude hold, speed hold and autothrust engaged.

The cabin service was commenced but as the rear flight attendant approached the centre of the aircraft, a loud banging noise could be heard from beneath the right wing, which was causing concern to some of the passengers. Conscious of not alarming the passengers further, she made her way promptly to the rear interphone and called the purser to report the noise. The purser informed the commander but instructed the rear cabin attendant to speak direct to the commander in order that the noise could be reported and discussed as accurately as possible. Having informed the flight deck of the situation in the passenger cabin and the loud banging noise the cabin crew abandoned the service and secured the cabin as instructed by the commander.

The purser was instructed to see if the right main landing gear door was visible from the cabin, which it wasnt. Following a discussion between the two pilots, it was agreed that they would inform ATC of their situation and request to hold at Seaford whilst they attempted to rectify the problems before returning to Gatwick. At about the same time, ATC at Gatwick were informed that a person who had observed the takeoff had seen something hanging from the aircraft. This information was passed to the pilots who explained their situation to ATC and their intentions to re-cycle the landing gear and return to Gatwick. A runway check was carried out during which tyre debris and a length of wire were found near the point of rotation on the runway. The aircraft was placed into an orbit in the area of Seaford and the crew carried out the Anti skid fault and Landing gear fails to retract items of the Quick Reference Handbook (QRH). The landing gear lowered and locked down successfully indicating three greens but the increase in vibration and noise was noticeable on the flight deck so the pilots decided to raise the landing gear. On this occasion the landing gear in transit lights extinguished. The purser confirmed that the noise had increased considerably and passengers reported having heard a groaning noise during the cycling of the landing gear.

After retracting the landing gear, the pilots concluded that a tyre had burst on the right main landing gear and that a section of rubber was trailing from the damaged tyre. However, they could neither determine whether one or both tyres on the right main landing gear had burst nor the degree of damage to the landing gear itself. Having re-assured the passengers, the commander briefed them of his intention to return to Gatwick. He then contacted the company engineers at Gatwick who, from the amount of tyre debris on the runway, deduced that only one tyre had burst. Following a discussion between the two pilots, it was agreed that they would return to Gatwick to land but they should try and establish if one or both tyres on the right main landing gear had burst, and the serviceability of the landing gear, before carrying out the landing. Their solution was to fly an ILS approach using the CAT 1 procedure but with a go-around at 100 feet on the radio altimeter. Engineers were to be positioned in order to observe the right tyres and try and see if one or both

had burst. Following the go-around, the crew intended to assess the information and review their options.

Having agreed their intentions with ATC the pilots prepared the aircraft for an ILS approach to Runway 08R at Gatwick. The weather at Gatwick was surface wind 040°/11 kt, variable between 350° and 060° with a visibility of 9,000 metres and broken cloud at 2,400 feet. On the base leg, the autothrust failed and despite a number of attempts to re-engage the system, it remained inoperative for the remainder of the flight.

The pilots decided to lower the landing gear later than normal in order to reduce the amount of time the damaged tyre was exposed to the airflow, so as to minimise the risk of a section of tyre tread separating and endangering persons or property below the flight path. The aircraft was fully configured for landing at about 2.5 nm DME following which the SPLR, MAN SPLR FAULT, ICE PROT and Q FEEL HTR FAIL caution lights illuminated. The pilots considered the implications of these cautions and decided to continue the approach. The landing gear was lowered successfully and the aircraft descended on the glide path to 100 feet radio altimeter height. At that height, the commander initiated a go-around and advanced the thrust levers to go-around thrust. After the go-around button was pressed, the autopilot (AP) and flight director (FD) systems both failed and the climb to 3,000 feet on runway heading was manually flown. Landing gear retraction was delayed until a height of 600 feet. During the go-around, the pilot of a stationary aircraft at the J1 holding point confirmed that one tyre had shed its tread.

After gear retraction, the right main landing gear in transit light remained on. During the go-around the MAN SPOILER FAULT and the Q FEEL HEATER FAIL caution lights extinguished. Later, during the climb out, both the autopilot and flight director systems were re-engaged and the aircraft was levelled at 3,000 feet. ATC confirmed that only one tyre had burst and the pilots decided to return to Gatwick and land. They decided not to recycle the landing gear on this occasion but again to delay lowering it until late on the final approach. The landing was to be made using minimum braking with the option to stop on the runway or turn off at exits CR or BR. The commander briefed the Purser that, in effect, it would be a normal landing but should anything untoward happen, the cabin crew were to follow the standard emergency procedures. The purser asked the commander if the cockpit door was to remain locked. He decided it would, as to unlock it would have meant one of the pilots having to vacate his seat, which the commander did not want at that stage. It was not deemed necessary to use the pre-planned emergency procedures or to have the passengers adopt the Brace Position. The commander then spoke to the passengers, giving them a clear and concise explanation of his intentions.

The aircraft was radar vectored for a CAT 1 ILS to Runway 08R and was configured for landing with the landing gear lowered slightly later than normal. The MAN SPLR FAULT and Q FEEL HTR FAIL cautions illuminated once more, prompting the pilots to consider again their implications. Airspeed was reduced towards a target of 5 kt above the reference speed for flaps 33° (VREF 33) which equated to 114 KIAS. At a height of 100 feet the airbrake was selected out with care so as not to move the actuating lever through the gate into the manual spoiler range. The surface wind for landing of 030°/13 kt assisted the pilot in touching down on the left main landing gear wheels first. The touch down was smooth and the right main landing gear was lowered onto the runway without delay. During the rollout there was very little extra noise or vibration on the flight deck. The aircrafts natural deceleration was assisted by gentle wheel braking and the headwind component. When the pilots had satisfied themselves that it was safe to do so, they taxied clear of the runway at exit BR.

ATC instructed the pilots to park the aircraft on Taxiway AS and subsequently they contacted the Airport Fire Service on the dedicated frequency. Having had the nose wheels chocked and established with the Fire Service that the aircraft was safe, the pilots shut down the engines and the passengers disembarked.

Main Landing Gear description

The twin-wheel Main Landing Gear (MLG) assemblies retract inwards into the fuselage. The MLG doors are mechanically linked to the landing gear so as to close only when the landing gear is retracted. Each MLG has two squat (weight on wheel) sensors. The squat switching circuits consist of two groupings of relays, designated system 1 and system 2. Within each system, primary relays control the operation of the aircraft lift spoilers, and also control groups of secondary relays to effect changes in the aircraft services when going from the on ground to the in-flight mode of operation and vice versa.

Aircraft examination

The right inboard tyre (No 3 position) had suffered major damage, including separation of its tread around 75% of its circumference (see figure 1 *(jpg 76kb)*). The separated length of tread had become jammed around the landing gear axle. Tyre debris and some wiring were recovered from the runway over a distance of around 500 metres, commencing 650 metres from the start of the take off roll. The tyre was deflated and had been holed; a braking flat had been worn through the tyre tread into the casing (see figure 2).

The top edge of the right MLG door trailing edge had suffered skin disruption and buckling covering an area of approximately 25 x 25 cm. The right MLG door attachment bracket was distorted and a hinged fairing above the right MLG door had suffered damage to the trailing edge. The right landing gear fairing panel located aft of the landing gear bay had been distorted over a small area. The right inboard flap section showed several impact marks and one area of physical damage where the skin had been deformed. There were marks on the lower right inboard lift spoiler surface and minor damage was found to the right wing-to-fuselage fairing panels. There was evidence of rubber impact marks to two right side passenger cabin windows above the MLG.

The right MLG strut had been damaged by flailing loose tyre tread, and there was a series of gouges around and under the four band clamps on the main strut; two band clamps had snapped as a result of the tyre tread impact. The outboard and inboard squat switch sensor wiring was broken in several places and had been stripped of insulation. Both power supply cables to the inboard and outboard brake fan motors were severed, rendering the fans inoperable. The wiring to the inboard brake temperature sensor was found to be open circuit, which resulted in a maximum temperature indication. The wiring to both the inboard and outboard antiskid wheel speed transducers was also damaged.

Tyre examination

The tyre was examined by the tyre manufacturer in the presence of an AAIB Inspector. The majority of the tread had separated at the original interface between the tread and casing; a long length of tread had remained attached to the tyre. Initial examination of the tread confirmed little wear consistent with the number of landings and although there were a number of cuts, there was no evidence to suggest complete penetration of the casing. A full reconstruction of the tyre tread sections was carried out on the casing which confirmed that the majority of the missing tread had been recovered in pieces from the runway.

Visual examination of the inner liner revealed that most of it was satisfactory apart from a break in the area of the braking flat. Air needle inspection of the intact areas of the liner using leak detection solution showed a single rapid leak within the lower sidewall on the outboard side of the tyre. The tyre was then sectioned around the area to examine the internal structure. It was evident that there was an area of casing break-up adjacent to the split in the liner which had propagated to a length of approximately 600 mm around the sidewall of the tyre. This casing break-up was caused by a fatigue failure originating from stresses on the tyre due to sidewall flexing, which eventually resulted in a break down of adhesion between the casing plies.

Tyre history

The tyre was originally limited to R5 (five retreads). This was reduced to R4 in October 2001 following discussions between the operator and the tyre manufacturer after the discovery of casing break-up on returned tyres at retread levels above R4 and sidewall blisters found in service. The No 3 tyre, serial no 99097415, was manufactured in April 1999. The tyre had initially been returned for investigation after its first service life and it was subsequently retreaded. However, the retread (R) status was not incremented. Since that first retread, it had acquired four more retreads. Thus when the tyre failed, it was designated R4 when the actual life of the tyre was R5. The tyre left the manufacturer on 25 March 2002 and was fitted to this aircraft on 7 May 2002. It had flown eight sectors prior to take off on the accident flight. The tyre pressures were checked on the morning of 8 May 2002 and were within the maintenance manual limits.

Manufacturers tyre inspections

Tyres are inspected after the manufacture/retread process using a Non-Destructive Test (NDT) technique known in the industry as shearography. This uses holographic laser imaging of surface displacement characteristics which reveals flaws in materials by looking for strain anomalies on the surface.

At the time the tyre was inspected for its fifth retread, the system used by the tyre manufacturer was approximately eight years old and until recently was considered to be the industry standard for aircraft tyre shearography. The machine took four images from within the centre of the tyre. However, after setting up a similar tyre and taking measurements to determine the systems coverage, it was apparent that the area of casing break-up was outside the coverage of that shearography system.

On 22 April 2002 (ie after the failed tyre was retreaded but before this accident) the tyre manufacturer introduced a new shearography machine which overcomes some of the limitations of the previous system by providing full 360o bead to bead coverage with improved digital imaging and fault definition.

Tyre failure analysis

The split in the liner was caused by a fatigue failure of the casing. This allowed pressure loss and subsequent deflation of the tyre causing excess heat to be generated during the taxi and take-off ground roll phases. This in turn caused a break down of tread adhesion which, together with the high centrifugal force near the aircraft rotation point on the runway, caused the tread to separate from the casing. On landing, the tyre was deflated or near deflated and the flailing tread jammed between the wheel and the axle, preventing the wheel from rotating and resulting in a severe flat spot worn through the tyre.

The manufacturers current shearography machine should detect the type of sidewall damage suffered by the accident tyre. Consequently, it is highly likely that a tyre carcass with similar damage would now be withdrawn before entering service.

Flight Recorders

The CVR and DFDR recordings contained time histories of the entire flight. The information on the recordings was time synchronised and then used to assist in the reconstruction of the history of the flight and to obtain a clearer understanding of the timing of the tyre burst event.

The CVR and DFDR recordings were uneventful until the aircraft reached rotation speed. As the call ROTATE was made, unusual vibration sounds were recorded on the CVR. The most prominent sound was associated with the rotational speed of the main landing gear wheels but sounds probably emanating from vibrating items in the cockpit and galley were also recorded. The non-handling pilot commented that THE SKID FAULT HAS COME UP. Subsequently the landing gear was selected UP and 15 seconds later, the non-handling pilot reported WEVE GOT ONE RED LIGHT ON THE GEAR.

The DFDR did not record any abnormality before or during the takeoff roll. The first unusual event was recorded at landing gear retraction when the landing gear discreet did not change state and the right main landing gear squat switch discrete remained set at a value equivalent to the aircraft on ground state.

Secondary failure indications

No faults were found when the gear uplock, gear downlock and door uplock sensors and their wiring were tested after the accident. Therefore, tyre debris probably prevented the door from locking correctly causing the damage to the MLG door structure and thus the right main gear status light continued to indicate red after the initial landing gear retraction.

Damage to the wiring to both right MLG squat sensors would have caused the system to default to the on-ground condition, resulting in a disagreement between the left and right MLG squat sensing. This condition would have caused the Q-feel pitot heater failure indication (Q FEEL HTR FAILURE) and the fault indication for the in-flight spoiler deployment protection system (MAN SPLR FAULT). The damage to the wheel speed transducers resulted in the illumination of the ANTI SKID FAULT and ANTI SKID INOP and there would have been no anti-skid braking protection on the right wheels.

Analysis of crew action

Apart from the shimmy experienced at rotation, the noise and vibration caused by the flailing tread of the burst tyre could not be heard or felt on the flight deck. The ANTI SKID FAULT and the right main landing gear still in transit light were considered by the flight deck crew as they occurred but since neither required immediate action, by maintaining the speed selected at 190 kt, the airspeed was limited to below the maximum landing gear extended speed of 210 kt.

The crew actioned the LANDING GEAR FAILS TO RETRACT emergency procedure in the QRH which required the normal landing gear selector to be placed in the down position and to confirm three green lights were illuminated. The landing gear lowered normally with only the usual amount of additional noise in the cockpit and the three green lights illuminated. Using the information passed by ATC and the company engineers regarding the debris found on the runway, the pilots correctly identified that a tyre had burst and was probably trailing the tread. They elected to retract

the landing gear in order to prevent any further damage to the aircraft due to the flailing rubber trailing in the airflow. On this occasion retraction was successful, with all landing gear in transit lights extinguished.

Having satisfied themselves that the burst tyre was the initiating event for the difficulty in raising the right main landing gear, the crew considered that the ANTI SKID INOP caution was caused by the damage created by the flailing tread on the landing gear assembly. The Q FEEL HTR FAILURE and MAN SPLR FAULT warnings that illuminated simultaneously on the first final approach were considered but since these malfunctions would not affect their planned go-around, they continued the approach.

Failure of the AP and FD during the go-around were probably due to the erroneous on ground condition caused by damage to the squat sensor wiring. The commander confirmed the failure to the co-pilot and manually flew the go-around, delaying landing gear retraction to a height of 600 feet in order to permit the engineer adequate time to inspect the tyres. Following landing gear retraction, the AP and FD were re-engaged.

The confirmation from the engineer that only one tyre had burst and the observation from the pilot of the aircraft at the holding point that the tread had been shed allowed the commander to brief the crew and passengers for the landing. With the surface wind 310° at 15 kt, the commander briefed the co-pilot that he would make the initial touchdown with the left main landing gear. He would then allow the right main landing gear to lower onto the runway followed by the nose landing gear using manual spoiler deployment in accordance with standard operating procedures and minimum braking.

Conclusions

Following the most recent retread of the No 3 tyre, a defect went undetected due to limitations of the NDT system used by the retread facility. This defect resulted in tyre deflation and tread separation during the take-off roll. Secondary damage was inflicted on the squat switch sensor wiring.

From meetings held with the operator, flight deck and cabin crews, supported by information from the CVR and DFDR, it was clear that the crew had correctly identified the burst tyre and flailing tread as the origin of their problems. The conflict created for the air/ground logic when the inboard and out board squat switch sensor wiring was disrupted led to the other caution messages and failures dealt with by the pilots. Having successfully lowered the landing gear, the pilots were concerned both for the potential damage which the flailing tread was inflicting, and the possibility that the tread would detach from the tyre endangering persons or property below the aircraft. For that reason, the landing gear was retracted except during the final approaches. Normally when the landing gear fails to properly retract, having successfully lowered the landing gear, it remains down.

The operator demonstrated that the locked door policy, which is not reproduced here, had the flexibility to support the requirements of an aircraft commander to have the door locked or unlocked across the range of possible scenarios.

Within the Flying Crew Orders, the operator had set out the policy regarding flypasts. The policy was:

> *Flypasts of the control tower, to obtain information on the status of landing gear, wheels, tyres, etc., should not be undertaken. Experience and research indicate that*

flypasts are unlikely to contribute any useful information to supplement flight deck indications.

Whilst the concern of the flight deck crew that the other tyre may also have been damaged was understandable, it was noted that the damaged tyre appeared to be inflated although it had burst, this was due to the rigid construction of the tyre. Whilst the low approach and go around determined that the tyre tread had been shed, it would not have been possible to establish whether the tyres were inflated or not. Whilst the operator understood and sympathised with the actions of the crew, the company policy on flypasts was reinforced by the difficulty in accurately establishing the inflation status of the tyre and the extent of the damage to the landing gear leg.

The operating company had recently been absorbed by another and the 146-RJ100 crews had only recently been instructed to adopt the new operators operating policies and procedures, of which the policy regarding flypasts was one. Under the circumstances, the flight crews deviation from company policy was understood and accepted by the new operator as a consequence of the recent merger.

Safety Actions

During certification of the BAe146/RJ series the manufacturer assessed the consequences of tyre failure. This Systems Safety Assessment (SSA) considered that two independent tyre failures would have to occur to cause damage to the squat and wheel speed transducer sensors on one side. In this case the systems were affected due to a single tyre failure which caused damage to the wiring to both sensors. In the light of this accident, the manufacturer is conducting a review of this SSA.