Department of Trade

ACCIDENTS INVESTIGATION BRANCH

British Airways Boeing 747-136 G-AWNA Report on the accident at Bombay Airport on 8 November 1975

Reprint of the report produced by The Civil Aviation Department of the Indian Government

LONDON
HER MAJESTY'S STATIONERY OFFICE

## List of Aircraft Accident Reports issued by AIB in 1978

No.	Short title	Date of publication
1/78	Bell 206 (Jet Ranger) G-BAYA at Loch Avon, Invernesshire January 1977	May 1978
2/78	Augusta Bell 206B G-AVSN DH 82A (Tiger Moth) G-ANDE collision at Biggin Hill Aerodrome, Kent May 1977	(forthcoming)
3/78	Piper PA E 23 (Aztec) Series 250 G-AYSF at Moffat Dumfriesshire Scotland July 1976	(forthcoming)
4/78	British Airways Boeing 747-136 G-AWNA at Bombay Airport November 1975	(forthcoming)

Note: This report is reproduced without the sketches and photographs referred to in the text of the technical report which is embodied in it.

## Report on accident to British Airways Boeing 747 aircraft G-AWNA

British Airways Boeing 747 aircraft G-AWNA met with an accident on 8 November 1975 at Bombay Airport.

The Director General of Civil Aviation has ordered the investigation of the accident under Rule 71 of the Aircraft Rules and appointed Shri V Chellappa, Director of Air Safety as 'Inspector of Accident' for the purpose of carrying out the investigation.

The investigation has been carried out in accordance with the standards and recommended practices as outlined in Annex 13 to the Convention of International Civil Aviation. The State of registry (United Kingdom) appointed an accredited representative assisted by an adviser, who arrived at the scene shortly after the accident occurred. Thereafter, the representatives as well as those representing the Operator (British Airways) fully participated in the investigation, and their comments have been taken into account in the preparation of the final report.

The co-operation and assistance is gratefully acknowledged in respect of Captain C C Allen and Mr C G Pollard of the Accidents Investigation Branch, United Kingdom, who had assisted in the investigation as accredited representatives of United Kingdom and who made a most valuable contribution for the compilation of this report.

It is also wished to thank the Royal Aircraft Establishment (RAE), UK, for their valuable assistance in carrying out a metallurgical examination of the failed parts and rendering a technical report.

The technical assistance and expertise provided by the British Airways team headed by Mr A Richardson, Senior Air Safety Officer is gratefully acknowledged.

Recommendation No. 1 made in this report, as an immediate precautionary measure after the preliminary investigation, has already been promptly implemented by British Airways in a suitable satisfactory manner. Air India have also suitably implemented the recommendation as a measure of abundant caution, even though they operate a different model of Boeing 747 aircraft, fitted with modified wheel assemblies and have experienced no similar incidents so far.

Recommendation No. 2 which involves introduction of a major modification, it is believed, is under examination by the Boeing Aircraft Company.

V CHELLAPPA DIRECTOR OF AIR SAFETY (Inspector of Accidents)

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## Aircraft Accident Report

Aircraft Boeing 747 - 136 G-AWNA

Engines Four Pratt & Whitney JT9D-7

Registered owner and operator

British Airways (BA)

Scheduled Service Bombay-Rome BA 979

DA 9

Commander First Officer

Senior Engineer Officer

Cabin staff

Passengers 288

Place of accident Bombay Airport - Runway 27

Time of accident 2220 hrs GMT

Date 8.11.1975

Weather conditions Night, calm wind, visibility 2500 M

Temp 21°c

## 1. Summary

During the taxi out from the apron to the threshold of runway 27, the No. 8 main wheel fractured. Consequently, a brake overheat warning light illuminated, which was not a true indication of the wheel failure. The Captain decided to return to the apron for an Engineering check of the wheel and continued taxying back via runway 27 with the permission of the Control Tower. This resulted in the frictional heat generating a fire at the wheel assembly which was noticed by the ATC. On advice from the ATC the aircraft was stopped on the runway and emergency evacuation of the passengers and crew carried out without any fatalities.

The Fire services promptly reached the scene of the accident and controlled the fire within two to three minutes.

The aircraft suffered extensive damage to the left body gear and wing root fairings.

## 2. Investigation

#### 2.1 Circumstances

The aircraft was operating Service BA 979 from Auckland to London via Melbourne, Hongkong, Bombay and Rome and arrived in Bombay at 2013 hrs GMT on 8.11.75. After a normal transit check, the aircraft was pushed back from Bay No. 10 and taxied out under its own power on the taxi track towards the threshold of runway 27. While taking a turn on the taxi track Bravo 3 before entering runway 27, the Pilot observed 'Brake overheat warning light' illuminated on the Cockpit panel and asked the Engineering officer to identify the wheel affected. The Engineering officer checked the annunciator panel and reported that No. 8 wheel (left body landing gear rear inboard wheel) was causing the overheat warning. The Pilot communicated to ATC that he would taxi back to apron via runway 27 to get the defect checked by the engineering. Tower cleared him to taxi but after the aircraft had taxied a distance of approximately 6400 ft on the runway, the Tower noticed an undercarriage fire. The Tower immediately informed the Commander of the landing gear fire and advised him to stop the aircraft and evacuate the passengers. The Captain stopped the aircraft, shut down the engines and ordered evacuation of the passengers. This was carried out in a satisfactory manner, except for seven passengers sustaining serious injuries during evacuation.

The Fire services reached the site of the accident in approximately one minute from the alarm being given and the fire was controlled within two to three minutes. A total of six fire tenders and two ambulances attended the aircraft. The fire was controlled by the use of dry chemical powder and foam followed by application of water to cool the heated areas.

#### 2.2 The ATC Transcript

Time	To	From	Text
2206	TWR	BA 979 TWR	BA 979 TAXI BA 979 CLEAR TO TAXI HOLDING POSITION RWY 27 TAXI VIA B1, B2 & B3
2207	TWR	BA 979 BA 979 TWR BA 979 TWR	ROGER 27, VIA B1, 2 & 3 BA 979 HAVE WE GOT CLEARANCE? BA 979 SAY AGAIN CLEARANCE STAND BY WE WILL ADVISE
	BA 979	TWR	BA 979 COPY CLEARANCE — BOMBAY CONTROL CLEARS BA 979 TO ROME VIA
2211	BA 979	BA 979	BA 979 CLEARED TO ROME SWD R19 CLIMB TO AND MAINTAIN LEVEL 310 AFTER TAKE OFF STRAIGHT 1,700 FT RIGHT TURN TO PICK UP RADIAL 274 DEGREES AND REACH 310 BY SWD.
2212	TWR	TWR BA 979 TWR BA 979	THAT IS CORRECT BA 979 READY FOR TO GO BA 979 CLEARED IN TO POSITION 979
2214	TWR	BA 979	979 BACK TRACK

Time	To	From	Text - topic (b)
2215	TWR	TWR BA 979	BA 979 CLEARED TO BACK TRACK BOMBAY TWR BA 979 SIR, WE HAVE GOT A TECHNICAL SNAG COULD WE BACK TRACK ON RWY AND COME BACK TO DISPERSAL
		TWR BA 979	PLEASE ROGER CLEAR TO BACK TRACK ON RWY 09 ROGER SIR
2218	TWR	BA 979 TWR	AM I CLEAR TO TURN OFF AT CHARLIE? ROGER TURN RIGHT TAXYWAY CHARLIE BAY
		BA 979	10 ROGER CHARLIE BAY 10 CAN I JUST STAND OUT AND JUST HAVE THE ENGINEERS COME UP AND HAVE A QUICK WORD WITH US?
		TWR BA 979	TAXI STRAIGHT AHEAD WE WILL ADVISE YOU ROGER
2219	BA 979	TWR	BA 979 YOUR UNDER-CARRIAGE IS ON FIRE SWITCH OFF YOUR ENGINES AND EVACUATE IMME
		BA 979 TWR	979 ROGER BA 979 EVACUATE YOUR PASSENGERS IMMEDIATELY
2220		BA 979 TWR	ROGER WE ARE DOING SO BA 979 FIRE SERVICES ARE COMING TO YOU
2222	BA 979	BA 979 TWR	BA 979

#### 2.3 Evacuation

After receiving the warning from ATC of the landing gear fire, the Captain ordered the evacuation of the passengers on the public address system. The Cabin crew followed the prescribed drill for evacuation following the operation of the evacuate alarm signal.

All the main Cabin doors were opened and the emergency slides deployed but No. 1 door left slide failed to inflate. The passengers at this exit were directed to door 1 right for evacuation. The evacuation of the 288 passengers through other serviceable 9 Cabin doors was carried out in a satisfactory manner and the numbers evacuated at each door was average with the load, and no particular door was taking more than another. The following few incidents pertaining to evacuation need mention:

#### (a) Door 2 right.

One passenger left the aircraft before the slide was fully inflated and received injuries. Passengers experienced difficulty in evacuation as they insisted on carrying personal belongings.

#### (b) Door 4 right

One lady passenger and one male passenger sustained injuries during evacuation. The male passenger insisted on carrying heavy personal belongings.

#### (c) Door 3 left

The aft wing slide door was destroyed by fire after the evacuation was completed.

#### (d) Door 4 left

There was confusion initially of passengers at this exit but evacuation was completed successfully. The stewardess received minor grazing on the leg and knees at the bottom of the slide.

The crew compartment door was not used. The technical crew evacuated via door 1 right.

## 2.4 Injuries to persons

Injuries	.Crew	Passengers	Others
Fatal	Nil	Nil	_
Serious	Nil	7	_
None	18	281	

#### 2.5 Damage to aircraft

#### (a) Fire damage

There was extensive fire damage in the belly area adjacent to the left body landing gear and wheel well. The outer skin had burnt out and the inner honeycomb panels were found charred. There was evidence that the fire had reached upwards up to the No. 3 door left.

The left hand body gear had been subjected to extreme heat. There was sooting on the fuselage side and eight cabin windows in that area were crazed due to the overwing slide burning.

The metal wheel hub had initially caught fire due to extreme heat generated by friction, until the tyre caught alight by leaking hydraulic fluid.

The hydraulic hoses in the area between No. 7 and 8 wheels showed evidence of severe fire damage and were dripping fluid.

#### (b) Other damage

The No. 8 main wheel hub was in three main pieces. The outer part of the hub was still attached to the tyre. The outer portion of the wheel drum was found burnt out and the wheel assembly shifted inwards towards the landing gear truck.

The tyre had deflated and the outer surface was damaged by fire. The inner bead seat area was melted out and the bead wires were found wrapped round the brake discs.

#### 2.6 Crew information

There was a crew change at Bombay Airport and the crew detailed to operate this flight was:

#### (a) Commander

Name: Captain J G Kemp

Licence: ALTP Licence No. 32299 endorsed in Group for Boeing 747 aircraft valid up to 8.5.79.

experience:

Flying Completed a total of 7128 hrs. 708 hours on B747 aircraft.

(b) First Officer

Name:

R D B Boulton

Licence:

ALTP Licence No. 81856 endorsed in group I for Boeing 747 aircraft valid up to 1.4.1978.

Flying

Total 3601 hours.

experience:

On B747 aircraft 1400 hrs.

(c) Senior Engineer Officer

Name:

S Clayton-Smith

Licence:

Flight Engineer 'O' Licence No. 1115 in Group I

for B747 aircraft valid up to 31.7.1978.

Experience:

Total 3328 hours.

On B747 aircraft 882 hours.

2.7 Aircraft information

Constructor's SI No.:

19761

Date of manufacture:

22.4.1970

C of A SI. No.:

2822

Date of renewal of validity:

15.4.1974 for 3 years

Total aircraft hours

16076

till the date of accident:

Any heavy landings involving the wheel hub whilst fitted to: G-AWNO G-AWNM Nil G-AWNA during the period 7.6.75 to

Normal transit check with only minor defects reported (not relating to landing gear or wheels) was carried out at Bombay and the aircraft departed from the apron at 2200GMT.

#### 2.8 History of wheel involved in the accident

Wheel serial no. 2266 was first received into service and fitted to G-AWNA position 1 on 7 October 1971. In 1972 an AD1 was received calling for a 'once off' eddy current check of the hubs. This check was carried out on 15 August 1973, at which time it had completed 1056 landings since new. At the time of the last tyre change 3 August 1975 it had completed a total of 2863 landings. It had been NDT<sup>2</sup> checked in the bead seat area and the valve but not adjacent to the bearings.

<sup>1</sup> Airworthiness directive

<sup>&</sup>lt;sup>2</sup> Non-destructive test

This wheel was then sent to Bahrain and held as a spare until 28 October 1975 when it was installed on G-AWNM. It was 'B' snagged to Base for NDT inspection.

It was removed from NM at London 29 October 1975 and was fitted to G-AWNA Nr 8 position on 1 November 1975. At the time of the accident it had completed 19 landings since the tyre was installed on 3 August 1975. Investigation has shown that the wheel was not subjected to crack checks between removal from NM and installation on NA.

The wheel was released to NA by the issue of a duplicate serviceable label issued by a Wheel Bay Supervisor (Mr J F Turner) on 30 October 1975 at the request of a Production Engineer (Mr A Davidson). Mr Davidson stated that he had a phone call from the Central Area stating that the serviceable label had been lost. He checked the history card before asking Supervisor Turner for a duplicate label. At the time of this check there was no record of the wheel having been fitted to G-AWNM two days before.

An ultrasonic check of the affected area was considered to be irrelevant at this stage because the recently issued Special Check of which these men were both aware, required this to be done at the next tyre change.

Note: At the time of the subject accident the situation in respect of the four incidents subsequent to NA January 1974 were still open with British Airways Engineering.

#### 2.9 Weather

Fair weather. Night, calm wind, visibility 2500 M, temp 21°C.

Weather was not a factor to the accident.

# 2.10 Aids to navigation

Not applicable.

#### 2.11 Communications

The two way communication between the aircraft and air traffic control was functioning satisfactorily.

## 2.12 Aerodrome and ground facilities

These were functioning satisfactorily and were not a factor to the accident.

# 2.13 (a) Flight Recorder beautiful by the part of the last state o

The 'Aircraft integrated data system' (AIDS) recorder installed on this aircraft does not record Brake temperature.

The information available from the read out of the AIDS recording, relevant to this accident, was:

(i) The aircraft commenced taxy-ing at 22.06Z and finally stopped for evacuation at 22.19Z.

(ii) The 'G' value for the previous landing was not abnormal.

#### (b) Voice recorder

The voice recorder tape was replayed. Due to interference and noises, it was not possible to make out a true and accurate transcript. However, the following are the notes taken as accurately as possible on the final part of the voice recording:

(22.12)	Speedbird 979 ready to go	
	979 cleared into position	
	Haven't been cleared to backtrack, have we?	
	Hello again	
	Same one is it	
	Hold it a bit before you go on	
	Same	
	Brake temperature alright though	
	That one's hot	
	Yes we have got a hot one	
	Left rear	
(22.13)	Brake overheat warning light	
	Right wing left brake full scale	
	right wing	
	979 are we clear to backtrack?	
(22.14)	979 cleared to backtrack	
	Do you want to go back?	
	got a fault	
	Think about it	
	Don't forget that Air France one	
	Right on top of the red	
	If it is drag affect the take off.	
	Let's taxi back	
	I think we ought to taxi back and have a look	
	Yes it looks like a genuine one	
(22.15)	We have got a brake overheat	
	Ladies and Gentlemen - Brakes overheating	
	returning the state of the stat	
(22.16)	Go straight down runway	
ikana me	It's a genuine one - It is getting hotter and hotter right into the danger z	ono
	Air France!	OHE
	I thought things were going too well!	
	It is a genuine one	

	I don't know
	Right in the danger zone
	May be a genuine one - Much rather to be sure
	After landing checks
	Still going up
	Are we clear to turn off the intersection?
(22.18)	Can I just stand off and Engineers - Taxi straight ahead
(22.19)	979 your undercarriage is on fire,
	Switch off your engine and evacuate.
	Ladies and Gentlemen undercarriage on fire - evacuate
	I repeat that evacuate the aircraft
(22.20)	Doors automatic
	Fire

#### 2.14 Wreckage

#### (a) Evidence retrieved from taxyway

The taxi track followed by the aircraft was closely inspected. The first indication of wheel failure was noticed on taxi track Bravo 3 approximately 2200 ft from the entry to runway 27. Considerable debris in the form of machined out alloy shavings and small broken pieces of heat shield, hub and bearings cage etc., were recovered in this area. These were followed by patches of oil stains, indicating heavy hydraulic fluid leakage in the area. As the aircraft taxyed further along the taxyway, burnt tyre/rubber marks and flat tyre impression started from a distance of 500 feet from the entry to runway 27 and continued on the runway for a distance of about 6,500 feet from the threshold, where the aircraft was finally stopped for evacuation.

From the ground markings observed on the taxyway the wheel appears to have failed after the aircraft had taxied for about 8,000 ft from the apron.

#### (b) Examination of the aircraft

The aircraft was moved from the runway and towed to the apron before the Air-India hangar where it was subjected to a detailed examination by the experts from Indian and United Kingdom Government Accident Investigation Branch and British Airways team.

The No. 8 main wheel hub was in three main pieces. The inner head seat was broken off due to machining action of the brake assembly end plate. The outer part of the hub was still attached to the tyre and the inner part located in a cocked condition over the brake piston assembly. The outer bearing was missing and the housing machined out approximately double the area. The axle nut, washer and inner ring of bearing were still located on the axle shaft but the anti skid drive hub was missing. The third piece was the part containing the inner bearing and it was inside the brake assembly.

The tyre showed no evidence of scuffs or damage and had deflated due to melting of the fusible plugs. The inner bead seat area was melted out.

The hydraulic hoses in the area between No. 7 and 8 wheels showed evidence of severe fire damage and were dripping fluid.

No. 1 hydraulic system pipelines on the left body gear to the tilt actuator and body gear steering were damaged by fire causing leakages which drained the system.

No. 4 hydraulic system brake pressure lines were damaged by fire causing leakage of fluid.

(c) Strip inspection of No. 8 wheel brake assembly

Damage observed on initial inspection of the brake assembly was as follows:

- 1. All rotor spline pickups were damaged and several were missing.
- 2. Heavy abrasive wear was observed on the lower arc of the static part of the assembly. This was heavier at the outer end of the assembly. The brake outer end plate appeared to have become molten in this arc.
- 3. Two of the ribs on the brake outer end plate at the upper point had picked up large quantities of what appeared to be aluminium alloy.
- 4. One segment of the No. 6 (outer end) rotor was missing.
- 5. The top part of the brake cylinder block had been worn away and the two bleed fittings were missing.

After strip, detail inspection revealed the following:

- 1. The brake stators had been worn in the lower arc.
- 2. All six brake rotors had cut into the torque tube splines in the lower arc. There was a linear reduction in depth of cutting from the No. 5 to the No. 1 rotor, the No. 6 rotor had cut to the same depth as the No. 4 rotor.
- 3. All stator lining pads were of serviceable thickness.
- 4. No rotors showed evidence of brake overheating.
- 5. All the rotor drive splines on the wheel rim had rotated helically about their inner attachment bolts and lay nested together at the inner end of the rim.
- 6. The wheel heat shield had been crushed and shredded, and fragments of it found throughout the brake assembly.

#### (d) Axle protection sleeve

After removal of the brake assembly from the truck it was noted that the axle protection sleeve had moved outwards and was not within positional tolerance. Its position was noted. Axial scratch marks on the axle beyond the inner end of the sleeve were noted and the sleeve was repositioned to just cover these marks. After resetting, the sleeve position was again established and found to be within setting tolerance.

As a result, the following observations were made:

- 1. Torque on hub nut required for resetting sleeve: 630 ft. lbs. approx.
- 2. Distance of sleeve migration 0.11 inch approx.

There was also damage caused by heavy abrasion on the underside of the axle protection sleeve. Furthermore, there was evidence of aluminium pickup on the underside of the sleeve just in from the outer bearing inner race.

There were some marks all around the centre portion of the sleeve which on first inspection appeared to have been made by the skidding and impact of rollers from the outer bearing.

The other three wheels from this truck were removed and the positions of the axle protection sleeves measured. Two of these had migrated outwards to a position outside the tolerance range for the fitting of a new wheel.

#### (e) Analysis

The damage observed is consistent with the wheel having moved inwards and upwards relative to the axle and tilting top inwards towards the truck. This appears to have been permitted by the splitting of the rear hub housing and bearing outer race, which allowed the housing and race to ride over the taper rollers. As the wheel moved inwards the inner hub failed circumferentially and the outer bearing slid down its rollers and the outer track shattered against the axle. From this point, the inner part of the wheel was supported by the brake rotors rubbing on the underside of the splined torque tube and the outer part of the wheel on the outer hub bearing housing rubbing on the underside of the axle protection sleeve. As the softer aluminium of the outer hub was churned away faster than the brake rotors out into the torque tube, the wheel tilted progressively more top inwards. At some stage the No. 6 rotor, which was bearing the greatest load, broke up and jammed against the torque tube splines. This caused the outer end rim spline attachments to fail, turning the rim splines helically and buckling the heat shield. The heat shield then became enmeshed with the brake and broke up. The brake end plate bottom edge then cut through the wheel rim and the wheel rim split into two halves and the end plate ribs at the upper point milled away the inner face of the wheel disc. The milling action of the brake end plate and the churning action of the axle sleeve on the wheel outer hub and disk heated the wheel material to the point where it appears to have caught fire. This fire was fed by hydraulic fluid which sprayed from the brake line on application of the parking brake and ultimately by the tyre itself catching fire. The fire was probably further fed by the failure of other hydraulic lines on the body gear, caused by heating.

#### 2.15 Tests and research

The damaged parts of No. 8 wheel and brake assembly involved in the accident were subjected to detail laboratory investigation at the Civil Aviation Technical Centre at New Delhi. Relevant extracts from the Technical Centre Report No. T N 131 of 1.1.1976 are reproduced below:

#### Visual Examination

Visual examination of the parts received showed, in addition to the fire damage, severe damage to the wheel and brake assembly. The more significant of these were:

- (i) The inner half of the wheel was sliced in two.
- (ii) The portion of the inner half of the wheel, housing the inner bearing, was separated by a complete fracture from the rest of the inner half of the wheel. The fracture has however followed a helical path at one stage (see sketch and photograph 1) in addition to the transverse separation (Photograph 2).
- (iii) Heavy abrasive wear damage was observed on the lower portion of the stators. This damage was highest at the outer end of the stator assembly.
- (iv) The torque tube bore evidence of 'cutting' action by the rotors (Photograph 3), the maximum being at the outer end of the torque tube.
- (v) The wheel bore evidence of burning.

- (vi) Apparent fatigue striations were observed on the fracture surfaces of the hub (Photograph 1).
  - (vii) The outer race of the *inner* bearing had split into two (Portions of the *outer* bearing were missing).

#### Microscopic examination

The failure of the outer race of the inner bearing was examined first. The fracture surface had no apparent evidence of fatigue. This part seems to have failed statically. Photograph 4 shows the location of the failure and photograph 5, the fracture surface.

On examination of the fractured surface of the hub housing the inner bearing (Item ii), it appeared as if there were two fatigue cracks (shown as 'a' and 'b' in sketch and photograph - 6) in the hub. The part was then cleaned and inspection showed that crack 'b' was only an extension of crack 'a'. Apparently the crack after originating at 'a' changed its plane of propagation at region 'c'. This is seen in photographs 7 and 8 which were taken after the fracture surface was cleaned.

The photograph - 9 shows a macrophotograph of the origin.

#### Discussions

From the failures and the nature of the fracture of the inner hub the probable sequence of failure is as follows:

- (i) The inner hub housing first failed due to fatigue perhaps causing the housing (and outer race) to ride over the bearing. (It is however difficult to say how much of the subsequent (transverse) failure of the hub was static failure as the surface has been badly damaged). The outer bearing hub and outer race slid down its rollers and rubbed against the axle leading to severe wear/abrasion damage to the hub.
  - (ii) At this point the inner part of the wheel was supported by the brake rotors rubbing on the under side of the splined torque tube. Evidence of such rubbing is clearly seen on the torque tube (See photograph 3). The outer part was probably supported on the outer hub bearing housing which was rubbing on the under side of the axle protection sleeve, (as already indicated in (i)). The aluminium of the outer hub was worn away by the rubbing action.
- (iii) The No. 6 rotor then failed. The keys on the wheel for engaging with the splines on the rotors failed, and then buckling of the heat shield occurred. The wheel rim was cut by the brake end plate and the outer stator(s). The fire developed as a result of heavy friction and over-heating due to this action. The hydraulic fluid (pouring out of the burnt hydraulic pipes) perhaps fed the fire.
  - (iv) It is noted that there is no sudden change of section or obvious stress raiser at the point of origin of the crack. The cause for the crack initiation at this point is therefore not clear. It is, however, noted that British Airways have informed that they have experienced very similar failures of the wheel hub in their aircraft.
- (v) It may be mentioned that examination of the axle after the incident at Bombay reportedly showed migration of the axle protection sleeve. If this migration was an indication of mis-setting of the sleeve, then this mis-setting could give rise to abnormal loads which in turn may conceivably have led to high stress in the area of fatigue crack initiation. This possibility may need to be examined as there is no apparent stress raiser in the region.

(vi) As the failed parts were to be sent to UK for further detailed metallurgical and other investigations, it was decided during the present laboratory examination not to make any detailed metallurgical investigation as it would have entailed cutting of the failed parts.

#### Conclusions

- (i) The failure of No. 8 wheel of B-747 aircraft G-AWNA was probably due to fatigue failure of the hub housing the inner bearing.
- (ii) It would be useful to determine if sleeve migration, if present, could have given rise to abnormal loads leading to the above fatigue failure.

The failed parts were then sent to UK for metallurgical examination at the Royal Aircraft Establishment, Farnborough. A Specialist officer from the Civil Aviation Dept. India was associated with the investigation in UK.

The relevant portion of the report ref. No. LSP 262/06/E916 of May 1976 of RAE is reproduced below:

"BRITISH AIRWAYS B747, G-AWNA. METALLURGICAL EXAMINATION OF PARTS FROM FAILED WHEEL.

Metallurgical examination has been carried out on the fractured inner hub and the AMS 6302 steel brake pad back plate from the No. 8 main wheel of the above aircraft, which was damaged during taxying at Bombay Airport.

#### HUB FAILURE

The damage to the wheel is known to have resulted from failure of the inner hub. This part, which was itself extensively damaged in the incident, is shown in figure 1. Though the majority of the fracture which separated the hub from the rest of the forged 2014T6 aluminium alloy wheel was devoid of useful features due to severe rubbing a portion of fracture face at approximately 45° to the circumferential rupture still retained clear evidence of fatigue. This region is arrowed in figure 1 and shown in greater detail, with the single origin arrowed, in figure 2. The actual point of crack initiation, which occurred in the ½" radius to an inner buttress, had been damaged, as can be seen in figure 3, but detailed examination of the adjacent machined surface, figure 4, showed that initiation had taken place in a defect-free region and had not been influenced by the machining marks. No evidence of further fatigue crack growth was found on any other part of the inner surface.

The fracture features exhibited by this hub are similar to those observed by the RAE Materials department on a number of other failed hubs from B747 aircraft. The initiation of fatigue cracks, at an angle of 45° to the axis of rotation, in the ½" radius to the internal buttress and in the absence of significant stress raisers can now be said to be characteristic of these failures. However, we have not found any metallurgical reason for initiation of these torsional fatigue cracks and must therefore conclude that their basic cause is of a mechanical nature.

#### BACK PLATE

The brake pad back plate is shown in figure 5. Part of the rim has been severely worn, presumably due to rubbing contact with the runway and, judging by discolouration around the worn rim, considerable heat was evolved in the wear process. Elsewhere on the plate, figure 6, there were agglomerations of aluminium that had been trapped against the radial ribs on the back of the plate and which appeared to have been molten or semi molten when deposited.'

## 2.16 Previous B747 main wheel failures experienced by British Airways

British Airways have furnished the following information on wheel failure experienced by them:

G-AWNA - London/New York - 28 January 1974

Take-off/wheel failure.

During take-off Nr 14 wheel failed. The crew were unaware of the incident until informed by ATC. During climb Nr 14 wheel brake temperature gauge indicated 4.00 units whereas all other brake temperatures were 2.00 units.

The inner half hub of Nr 14 wheel assembly had failed, the outer bearing had disintegrated and the wheel had seized onto the brake. The tyre was scuffed and deflated.

There was a fatigue crack on the inside of the inner half of the hub adjacent to the bearing.

Total landings : 1364

Landings since last tyre change. : 58

G-AWNO - London/Montreal retd apron - 10 December 1974

Taxying/wheel failure

As the aircraft was being pushed back from the stand Nr 15 wheel failed. There was a fatigue failure of the hub in the form of a crack that extended about two-thirds of the way round the hub.

Total landings : 1412
Landings since last tyre change : 81

G-AWNK - Zurich/Nairobi - 3 January 1975

Taxying/main wheel failure

As the aircraft was being pushed out prior to starting engines Nr 1 main wheel failed. There was a fatigue crack on the inside of the inner half of the hub adjacent to the bearing.

Total landings : 1908 Landings since last tyre change : 52

G-AWNL - London-Miami - 16 August 1975

Take off/wheel failure

During the take-off run Nr 8 main wheel failed in the region of its inner bearing and most of the rollers and the outer track from the outer bearing fell onto the runway. The bearing boss on the inner wheel half had failed from a fatigue crack.

Total landings : 2119
Landings since last tyre change : 33

G-AWNJ - London/Nairobi returned to apron - 16 September 1975

Taxying/Wheel failure

During pushout at London Nr 13 main wheel failed. A fatigue crack on the inside of the inner bearing area developed until final failure occurred.

Total landings 2458

Landings since last tyre change : 80

The Engineering report relating to the wheel failure incident on aircraft G-AWNO on 10.12.1974 mentioned above was received by British Airways Air Safety Branch on 16.4.75.

The report concluded that the failure of the hub resulted from a growth of fatigue cracks under the influence of stresses, concentrated in the half-inch inner radius of the hub.

In the light of this report the Safety Branch suggested on 21 April 1975 that a fatigue life be established for the wheel and queried the efficacy of the NDT checks.

No action was taken in respect of this request until after the wheel failure on aircraft G-AWNL on 16.8.75. Following this incident, inquiries revealed that the proposed NDT check of the wheels adjacent to the bearings was not being carried out and an Engineering meeting was eventually held on 10.9.75. This meeting concluded that immediate adjustments were required to the Overhaul Manual, the approved maintenance schedule and the relevant worksheets in respect of wheel rim and barrel NDT inspections at each tyre change.

On 29 September 1975 a special check B747/75/84 issue 2 was issued to have all 747 wheels NDT checked in the area adjacent to the bearing at the next tyre change.

At the time of the subject accident (8.11.75) the situation in respect of the four incidents subsequent to G-AWNA January 1974 was still the subject of discussion between the British Airways Engineering and Air Safety branches.

#### 2.17.1 Brake temperature monitoring system

The brake temperature monitoring system comprises the following:

- (i) *Pilot's indicator light* A brake overheat indicator light at the Pilot's Instrument Panel (Annunciator) illuminates when the brake is too hot. This gives the Pilot a possible hazardous situation.
- (ii) Brake temperature indicator unit The brake temperature indicator unit is used for monitoring the brake temperatures. This is located on the Flight Engineer's Instrument Panel. It has an amber brake overheat light, a test switch and four selector switches. Two vertical scale temperature indicators, one for each gear (body and wing) are mounted on the panel assembly. The meters are colour-coded to designated temperature ranges. The red indication which is for an unsafe condition is for temperatures over 700 to 1,000° F.
- (iii) Flight Engineer's brake overheat light This illuminates when brake temperatures are high. If no wheels switches are depressed the overheat light monitors all brakes. If any wheel switch is depressed the overheat light only monitors wheels selected.

(iv) Wheels switches - Each switch when pressed and illuminated selects the four wheels to be monitored by the brake temperature indicators. When no wheels switches are depressed the brake temperature indicators are inoperative.

An inoperative channel (due to any defect) is indicated by a full scale deflection without an overheat light or a below scale indication.

There is also a test switch incorporated in the system for testing the functioning of the circuit.

Boeing, *vide* their Field Service Memorandum No. M7110-1169E/75/461 dated 12.1.75 on brake temperature indicating system on Boeing 747 aircraft have clarified the purpose and functioning of the brake temperature monitoring system. The following are reproduced from the above memorandum, which are relevant to the issue:

#### 'BRAKE TEMPERATURE INDICATING SYSTEM

In view of several inquiries regarding the subject system the following guidelines have been prepared and are being forwarded for your information:

The brake temperature monitor system is designed to provide flight crew with a measure of the brake energy absorption during brake application particularly during landing. This indication does not reach stabilized value for approximately ten minutes after brake energy absorption. Delayed indication is still timely for crew determination of approximate brake cooling interval required prior to takeoff. As indicated by recent experience, the brake temperature monitor system has very limited capability for providing immediate or reliable indication of tyre or hydraulic fluid fire, wheel bearing problems or wheel fracture.

If, in spite of its limitations, the brake temperature monitor system is used at an operator/s discretion as the basis for operational procedures related to brake problems, the following information is pertinent:

Normal braking operations of the aircraft will tend to cause the indicated brake temperature variations for individual wheels to follow a similar pattern when no abnormalities in the brakes exist. Substantial departures of one wheel channel indication from the temperature variation pattern observed for the remainder of the wheels can indicate that some type of abnormal condition exists. In such cases the differential temperature is of more significance than the absolute value. For the case where no substantial data exists we suggest the Captain may continue to taxi with a brake channel indicating overheat providing affected brake temperature is monitored, and taxi discontinued if brake temperature is rising steadily and/or the brake temperature monitor exceeds nine on the scale. A full scale brake temperature monitor reading indicates brake may have absorbed sufficient energy to deflate tyres./Melt fuse plugs.

It is our opinion that in the event a brake overheat light illuminates after the takeoff has been initiated, the Captain should not abort the takeoff for that reason alone. When Airborne, the normal in-flight procedures for brake cooling should be followed. The brake temperature monitor system will not respond quickly enough to detect any abnormal brake condition which might occur during the take-off roll.'

## 2.17.2 Failure of No. 1 door left emergency slide

The slide was last overhauled in February 1974 and was fitted to Door 1 left on G-AWNA in April 1974. It had remained in this position up to the date of the accident.

On investigation the failure of the slide to inflate at the time of the evacuation was established as due to a broken connection on the right hand aspirator assembly injector manifold at the point where the gas generator hose connects to the manifold, the metal section having sheared off close to the bell mouth. This would allow the gas generator charge to be vented to atmosphere.

The pipe connection failure probably occurred during the packing of the slide. The right hand aspirator assembly was also found incorrectly aligned on the slide, being two stud holes out. This also could have contributed to the failure.

## 2.18 Survival aspects

The accident was survivable. The Cabin crew discharged their duties in an efficient manner and the evacuation proceeded smoothly and satisfactorily.

Of the seven seriously injured passengers:

Two jumped or were pushed out of the door before the slide fully deployed.

One was unable to rise from the bottom of the slide before being hit by a succeeding passenger, due to the weight of the cameras round his neck.

One collided with a passenger at the base of a slide, then walked on broken glass.

Two sustained leg or foot injuries on contacting the ground at the base of a slide.

One was knocked or jumped on at the base of a slide by another passenger.

### 2.19 Aircraft loading and documentation

According to the load distribution sheet compiled for the flight:

(a) Aircraft taxi weight leaving apron : 324,468 Kgs.

(b) Estimated fuel burn off for taxy-ing: 1,000 Kgs.

(c) Estimated take off weight : 323,468 Kgs.

has been metiated, the Captain should not about the takeout for that reason alone, When

The loads on the aircraft were within permissible limits and safely distributed.

The certificate of maintenance was issued on 31.7.1975 valid for 2400 hours, out of which 1292 hours were completed at the time of the accident.

## 3. Analysis

Co-relating the ATC tape transcript with the cockpit voice recording, the following appear to be the sequence of events from the time the aircraft left the apron till it was stopped on the runway 27 for evacuation:

At 2206 the aircraft was cleared to taxi.

- At 2213 Brake overheat warning light illuminated on the Pilot's panel. The aircraft had taxied approximately 8,500 ft. on the taxi track by then and was approximately 500 ft. from the entry to runway 27.
- At 2214 The Tower cleared the aircraft to back track on the runway for positioning itself for take off. The Flight Engineer checked and found that No.8 wheel was causing overheat warning. At this juncture, the pilot on the advice of the Flight Engineer decided to return to the apron for an engineering check.
- At 2215 Pilot announced on the public address that he was returning to the apron due to brake overheating.
- At 2216 Tower permitted the aircraft to 'go straight down runway'.
- At 2219 Tower alerted the aircraft of the undercarriage fire and advised evacuation.

It is, therefore, evident that:

- (a) The No.8 wheel hub failure occurred after the aircraft had taxied covering a distance of about 8,000 ft. from the apron in about 6 minutes time;
- (b) The aircraft further rolled for about 500 ft. in one minute when the brake overheat warning light illuminated.

There was conversation in the cockpit that the temperature was rising and if the brakes were to drag it would affect the take off. The mishap to Air France B747 aircraft a few months earlier involving undercarriage fire was at the back of the mind of the crew and it was decided to have an engineering check of the wheel before take off.

Then the aircraft was taxied on the runway to return to the apron. This continued rolling on the collapsed wheel generated considerable amount of heat due to friction, causing the tyre to catch fire which was further aggravated by the hydraulic fluid leaking from the brake bleed ports and damaged brake hoses.

During strip inspection of the failed wheel at Bombay, there were two apparent fatigue fractures noticed on the inner hub, which appeared to have progressed to the extent that the hub split and was forced inwards over the inner bearing.

Subsequent laboratory examination of the fractured inner hub structure at the Technical Centre, New Delhi, also led to the conclusion that the failure of the wheel was probably due to fatigue failure of the hub housing the inner bearing.

The Royal Aircraft Establishment UK, who carried out metallurgical examination of the fractured inner hub, expressed the opinion that the fracture features exhibited by this hub were similar to those observed by them on a number of other failed hubs from B747 aircraft. They could not find any metallurgical reason for initiation of these torsional fatigue cracks and therefore, concluded that the basic cause was of a mechanical nature.

Had the Engineering Division of British Airways been more prompt in their investigation of the earlier B747 wheel failures, it seems highly probable that, as recommended by the Company's Air Safety Branch, they would either have established a fatigue life or else introduced suitable crack detection tests for the wheels considerably earlier than was actually the case. The early implementation of either of these remedies might possibly have prevented the occurrence of the accident.

The examination of the wheel axle at Bombay revealed that the axle protection sleeve had moved outwards and was not within positional tolerance. This wheel was fitted to aircraft G-AWNA on 29.10.75. If the wheel had been fitted with the sleeve in that position, adequate bearing preload may not have been obtainable and this may have permitted the wheel to float. This would have given rise to abnormal loads leading to fatigue crack initiation. However, the following reasons would appear to militate against this possibility:-

- (i) Two of the other three axle sleeves on the same truck were also found to have migrated similar amounts. Therefore, sleeve migration most probably occurred in service since the last wheel change. Once a wheel bearing has been set up, the migration of the sleeve cannot disturb it.
- (ii) Sleeve migration was a known occurrence and the relevant sections of the maintenance manual refer to the repositioning of the axle sleeve during wheel change. Boeing have issued a Service Bulletin to overcome sleeve migration. British Airways Engineering News issued as recently as October 75, contains clear and specific information on sleeve migration and repositioning the sleeve at the time of wheel fitment. Therefore, it is highly improbable that the maintenance personnel would have overlooked this important aspect at the time of last wheel installation at a British Airways base.

On the other hand it must be appreciated that the axle sleeve had migrated 0.11 inch from its correct setting position and the torque required to reset it was extremely high (it is accepted that the sleeve may have tightened as a result of the accident). Although there is no information available on the rate at which axle sleeves migrate, it is very difficult to accept that this amount of migration could occur on such an apparently tight fitting sleeve in only 19 landings. It must therefore be accepted as an alternative possibility that the sleeve was not correctly set at the last wheel change and that as a result, adequate bearing preload was not obtainable.

In regard to the brake temperature indicating system on Boeing 747 aircraft, Boeing have made it clear in their Field Service Memorandum on the subject that the brake temperature monitor system has very limited capability for providing immediate or reliable indication of fire or hydraulic fluid fire or wheel bearing problems or wheel fracture. In view of this and the fact that there were no operational instructions at the time of the accident requiring the Pilot to discontinue taxi-ing in case the brake overheat light illuminates, the Pilot was justified in continuing the taxi-ing after illumination of the brake overheat light. He took a wise decision to return to the apron for an Engineering check up of the wheel causing overheat indication.

The Pilot took prompt action to stop the aircraft, engines and evacuate the passengers. The injuries sustained by the seven passengers during evacuation were mostly attributable to their haste in getting out of the aircraft and entangling themselves with the baggage carried by them.

The Air Traffic Control at Bombay was vigilant and Fire Services responded to the emergency in a splendid manner. The fire was controlled promptly and efficiently preventing possible loss of life and major damage to the aircraft. The Cabin crew, who could not see the exact location of the fire at initial stages, deployed the escape slide of No.3 door left, which was destroyed by fire, fortunately after the evacuation was completed. The escape slide at Door No.1 left could not be deployed due to a mechanical defect.

## 4. Findings

Based on the scrutiny of documents furnished by British Airways, the statements made by the crew and passengers, the technical investigation of the failed parts and inspection of the wreckage, the following findings are made:

- (1) The Pilot and crew held valid licences and qualified fully to undertake the flights on B747 aircraft.
- (2) The aircraft was loaded properly and the load distributed in a safe manner. The loading and the centre of gravity position, recorded in the load sheet, were within permissible limits.
- (3) The aircraft was maintained and certificated in accordance with the approved maintenance schedule.
- (4) There was no recent previous report on the mal-functioning of the brake system and no major adjustments or replacements in the brake system have been made.
- (5) The transit visual inspection carried out at Bombay did not disclose any obvious defects with the wheel assemblies.
- (6) The wheel assembly was last serviced, crack detection carried out in accordance with the BA Schedule and certified on 3.8.75 at London. Crack detection had been carried out in the bead seat area and the valve but not adjacent to the bearings. There was no requirement then in the approved schedules for a crack detection test in the bearing area.
  - The wheel had made 19 landings since the last crack detection test on 3.8.75. No heavy landings involving this wheel were recorded during this period.
- (7) There was a fatigue crack in the inner bearing hub area in the wheel, which progressed to a complete wheel failure during the taxi to the runway from the apron.
- (8) The metal shavings and hydraulic fluid puddles found on the taxi track B-3 were indicative of progressive disintegration of the wheel assembly.
- (9) Fatigue cracking in the inner radius of the wheel inner bearing area was a known defect from 1972.
  - A number of previous wheel failures investigated by British Airways were all attributable to fatigue cracking in the area of the inner hub.
- (10) If the British Airways investigation into the previous wheel failures had been conducted with greater urgency and the crack detection check at the wheel inner bearing area at each tyre change had been included promptly in the maintenance schedules concerned this wheel failure might have been avoided. However the possibility cannot be excluded that in this instance the fatigue cracking may have been initiated as a result of incorrect setting of the axle sleeve at the last wheel change.
- (11) In the majority of cases recorded by British Airways the wheel brake temperature gauge did not give warning of the impending failure, probably because there was not sufficient time for a heat build up.
- (12) The Commander took a decision to taxi the aircraft back to the apron to get the wheel assembly checked by Engineering, as the Engineering Officer had advised him that it was an abnormal indication of brake overheat temperature on No.8 wheel.

- (13) According to Boeing, the brake temperature monitor system has a very limited capability for providing immediate or reliable indication of fire or wheel fracture and it has been designed only to provide flight crew with a measure of brake energy absorption particularly during brake application during landing. Therefore, the brake overheat warning was not taken as an indication of impending wheel failure by the Pilot.
- (14) Though the brake temperature monitor system was an optional item on early production aircraft, Boeing have included this system in the basic B747 aircraft specification since August 1973. All B747 aircraft operated by British Airways have this system fitted.
- (15) The landing gear fire was first observed by an alert Air Traffic Control Officer, who advised the Pilot promptly to stop and evacuate the aircraft. The Captain's decision to comply with this advice was correct.
  - (16) The fire and rescue services reached the site of the accident without delay and quickly and efficiently controlled the fire.
  - (17) The evacuation of the passengers was dealt with in a prompt and efficient manner.
  - (18) Seven passengers were seriously injured during the evacuation mainly due to their haste in getting out of the aircraft and getting entangled with their own baggage.
  - (19) No.1 door left emergency slide did not inflate due to a mechanical fault.

## 5. Cause of the Accident

Consequent to No.8 wheel failure during taxying of the aircraft the brake overheat warning light in the cockpit illuminated. This did not provide a true indication of the wheel failure to the Pilot, who, however, decided to return to the apron for an Engineering check of the wheel. The continued rolling on the collapsed wheel generated excessive frictional heat which, fed by leaking hydraulic fluid, resulted in the wheel assembly catching fire.

The wheel failure was attributable to fracture of the inner hub due to a fatigue crack.

## 6. Recommendation

(1) As a result of the preliminary investigation, it became evident that an immediate precautionary measure was necessary to prevent further incidents under similar circumstances. Therefore, in consultation with the United Kingdom accredited representative and the British Airways' representative, the following recommendation was made as an immediate precautionary measure on 11.11.75, which was duly conveyed by signal to the concerned authorities in UK:

PRELIMINARY INVESTIGATION INTO THE ACCIDENT TO A BOEING 747 AIRCRAFT REVEALS WHEEL FIRE CAUSED BY PROBABLE FAILURE OF THE HUB (. ) CONSEQUENTIAL DAMAGE RESULTED IN BRAKE OVERHEAT WARNING LIGHT COMING ON DURING TAXY-ING AND SUBSEQUENT WHEEL FIRE SIGHTED BY THE CONTROL TOWER WHO ALERTED THE AIRCRAFT (. ) AS A PRECAUTIONARY MEASURE IT IS RECOMMENDED THAT PILOTS SHOULD BE ADVISED TO STOP THE AIRCRAFT FOR CLOSE VISUAL INSPECTION IN CASE OF OVERHEAT BRAKE WARNING CAUSED BY INCREASE IN TEMPERATURE ON ANY ONE WHEEL.

By way of clarification, it may be mentioned that the increase in temperature on any one wheel mentioned in the signal above refers to an isolated increase in temperature on one wheel only.

British Airways took prompt action to implement this recommendation by issuing Operation Notice No.73/75 replaced by Notice No.79 of 75 dated 5.12.75.

Similar action was also taken by Air-India by letter ref. No.INT/A-18/747/76 dated 18.3.76 issued by the Operations Manager (Hqrs.) addressed to all Pilots/Flight Engineers.

(2) It is considered desirable that heavy transport aircraft, especially those fitted with Bogie undercarriages, be provided with a suitable warning system to alert the pilot of wheel failure/wheel fire.

30 November 1977

(V CHELLAPPA)
INSPECTOR OF ACCIDENT
(Director of Air Safety)