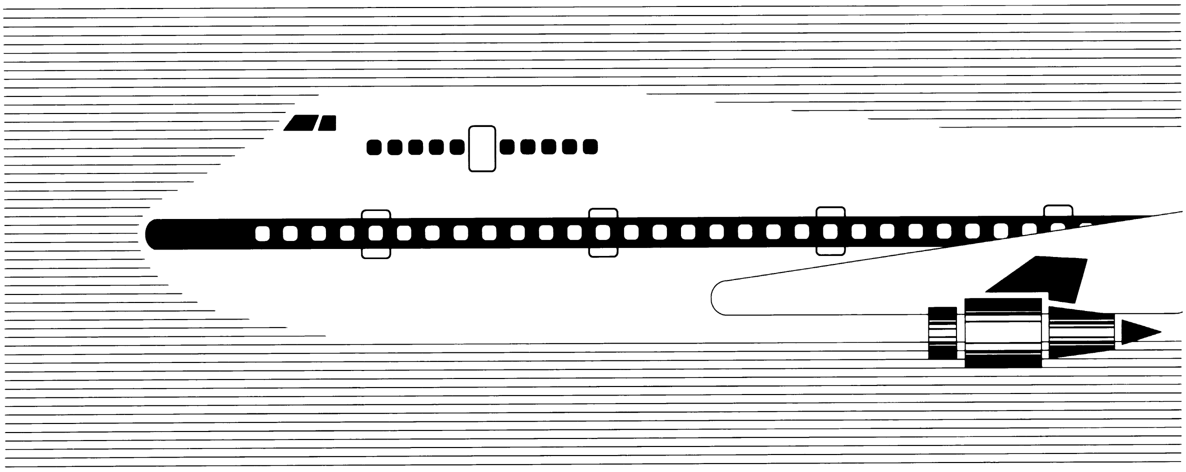
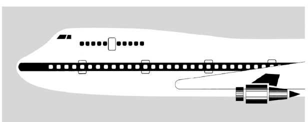
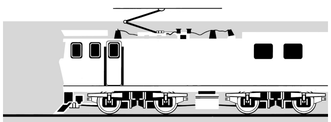
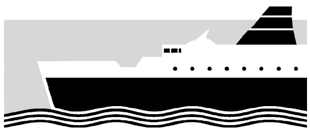


AVIATION OCCURRENCE REPORT

02-010 **Boeing 747-419 ZK-NBS flight NZ 2, in flight flap separation over Manukau Harbour by Auckland International Airport** **30 August 2002**







TRANSPORT ACCIDENT INVESTIGATION COMMISSION
NEW ZEALAND

Report 02-010

Boeing 747-419

ZK-NBS

flight NZ 2

in-flight flap separation

over Manukau Harbour by Auckland International Airport

30 August 2002

Abstract

On Friday 30 August 2002 at 2120, ZK-NBS (flight NZ 2), a Boeing 747-419, took off from runway 23 at Auckland International Airport for Los Angeles. On board were 355 passengers and 17 crew, including 3 pilots on duty in the cockpit.

During a left turn shortly after departure at night, with the flaps still extended to the take-off setting, about 70% of the right inboard trailing edge fore flap separated from the aircraft. The pilots did not receive any cockpit indications of anything untoward and only felt some slight bumps they thought to be from turbulence. The crew were unaware of the separation until the landing approach at Los Angeles some 12 hours later, when the flaps were selected for landing. The pilots took the appropriate action and carried out a go around procedure. The aircraft was repositioned for a further approach and landed safely. The safety of the aircraft and its occupants was not compromised by the incident. No one was injured.

The flap separated because its inboard attachment link failed. The link failed because a pre-existing stress corrosion crack had grown to a critical size, probably in a short period of time. The operator had inspected the flap assembly routinely and specifically as the aircraft manufacturer required, but neither the start of the crack nor its growth could be detected during those inspections.

A safety issue identified was the design adequacy of the fore flap attachment links. The aircraft manufacturer has completed a design change to overcome the limitations of the links.

Contents

Figures

Abbreviations

AD	airworthiness directive
amsl	above mean sea level
ATC	air traffic control
CVR	cockpit voice recorder
DFDR	digital flight data recorder
EICAS	engine indication and crew alert system
FAA	Federal Aviation Administration
FTD	Fleet Team Digest
ILS	instrument landing system
ISAR	In-Service Activity Report
km	kilometre/s
nm	nautical mile/s
NTSB	National Transportation Safety Board
QRH	quick reference handbook
UTC	coordinated universal time

Glossary

Clevis	A U-shaped connection
Cycle	A take-off and landing
Fretting	Damage, wear or consumption by hammering, gnawing, rubbing or irritating
FLAPS DRIVE	Indicates a trailing edge flap asymmetry condition, or a leading or trailing edge drive failure, which cannot be corrected by use of electric motors, has occurred
Missed approach	A go-around procedure when an approach is discontinued
Peen	To shape or form by striking

Data Summary

Aircraft registration:	ZK-NBS
Type and serial number:	Boeing 747-419, 24 386
Number and type of engines:	4 Rolls-Royce RB211-524G
Year of manufacture:	1989
Operator:	Air New Zealand Limited
Date and time:	30 August 2002, about 2122[1]
Location:	over Manukau Harbour by Auckland International Airport latitude: 37° 03´ south longitude: 174° 44´ east
Type of flight:	Air Transport
Persons on board:	crew: 17 passengers: 355
Injuries:	crew: nil passengers: nil
Nature of damage:	loss of right inboard trailing edge fore flap, and minor other aircraft damage
Pilot in Command's licence:	Airline Transport Pilot Licence
Pilot in Command's age:	58
Pilot in Command's total flying experience:	21 400 hours (2600 hours on type)
Investigator-in-charge:	K A Mathews

Acknowledgements

The Commission acknowledges the assistance provided by the United States National Transportation Safety Board and the Australian Transport Safety Bureau.

[1] Times in this report are New Zealand Standard Time (UTC + 12 hours) and are expressed in the 24-hour mode.

Factual Information

1.1 History of the flight

1.1.1 On Friday 30 August 2002 at 2120, ZK-NBS, a Boeing 747-419 (flight designation NZ 2), took off from runway 23 at Auckland International Airport for Los Angeles. On board were 355 passengers and 17 crew, including the captain, a first officer and a second officer on duty in the cockpit. The captain was the pilot flying. Among the passengers was an off-duty Boeing 747-400 captain.

1.1.2 ZK-NBS had Flap 20 selected for the take-off. The aircraft took off normally, in darkness, and its undercarriage was retracted shortly after the take-off. About one minute later when the aircraft was 1300 feet above mean sea level (amsl) it began a left climbing turn towards the northeast. The captain said the plan was to retract the flaps as the aircraft accelerated.

1.1.3 The aircraft indicated airspeed was around 200 knots for the departure and initial turn. The speed had increased to about 210 knots by the time the aircraft reached 1550 feet amsl and had turned through about 40°, with the flaps still selected to Flap 20. At about this point the pilots felt a slight bump, as if the aircraft had flown through some light turbulence. They were discussing this among themselves when about 15 to 20 seconds later they felt another similar bump. Because the bumps were out of context with the atmospheric conditions that night, the first officer asked the air traffic controller if there had been any other traffic in the area that could have generated some wake turbulence. The controller advised that there was no other traffic in the area.

1.1.4 There were no cockpit or other indications of anything untoward, and the flaps retracted normally with no indication of a problem so the captain decided to continue with the flight, putting the bumps down to atmospheric turbulence.

1.1.5 Some of the cabin crew and passengers felt and mentioned the bumps, so the Purser contacted the pilots and enquired about them and was reassured. The off-duty captain travelling as a passenger was seated with his wife just behind the flaps on the right side, and they too had felt the bumps. He said his wife enquired about them, but he did not think the bumps were significant and was not concerned that there was any problem with the aircraft.

1.1.6 The aircraft climbed normally to its cruising altitude and proceeded uneventfully to Los Angeles. During the 12-hour flight there was no performance loss nor anything out of the ordinary noticed that suggested there was a problem with the aircraft.

1.1.7 Approaching Los Angeles the captain slowed the aircraft to 250 knots and descended it to 7000 feet amsl for a standard arrival. Flap 1, which activates the leading edge flaps only, was selected at 7000 feet. Flap 5 was selected at 220 knots, followed by Flap 10 (a normal configuration for manoeuvring) at 215 knots, still with no indication of any aircraft problems.

1.1.8 Air Traffic Control (ATC) initially cleared NZ 2 to descend to 3500 feet and to intercept the localizer for an Instrument Landing System (ILS) approach. The aircraft was slowed to 190 knots, was established on the localizer and had begun to intercept the glide slope, when the captain called for Flap 20 and the Undercarriage, at about 2500 feet.

1.1.9 After the first officer had selected Flap 20 and before she selected the undercarriage down, a caution message appeared on the cockpit engine indication and crew alert system display (EICAS), with the words FLAPS DRIVE[2]. An expanded flap position indication appeared on the EICAS (see 1.4.15). The captain gave his Quick Reference Handbook (QRH) to the second officer to reference regarding the EICAS message. The captain said that because it was not an

[2] Indicates a trailing edge flap asymmetry condition, or a leading or trailing edge drive failure, which cannot be corrected by use of electric motors, has occurred.

appropriate time to troubleshoot a potential problem he asked the first officer to advise ATC of the situation and to request a missed approach[3]. The undercarriage remained selected up.

1.1.10 ATC cleared NZ 2 for the missed approach, advising the pilot to track via the localizer and to initially climb to and maintain 2000 feet. The missed approach was started as the aircraft neared 1700 feet. The flaps were left selected to Flap 20 (because of automatic flap asymmetry protection the inboard trailing edge flaps had not extended beyond Flap 10). ATC then directed the aircraft out over the ocean and away from the aerodrome so the pilots could investigate the problem. ATC asked to be kept informed and to be advised when the captain wanted to return NZ 2 for another approach to land.

1.1.11 As the aircraft crossed the coast, the aircraft captain made an announcement over the public address system advising the passengers and other crew of the situation. The off-duty captain saw that something was amiss with the right inboard fore flap, so he went to the left side of the aircraft to view the left flap system and to compare it with what he had seen on the right. Once he had made the comparison it was obvious a large section of the right inboard fore flap was missing. He then telephoned the cockpit and spoke to the second officer, telling him what he had seen.

1.1.12 The aircraft captain invited the off-duty captain to the cockpit to discuss the situation, and sent the second officer down to the passenger cabin to further examine the flaps. The pilots faced a dilemma that the QRH procedures called for the flaps to be set to Flap 25 for the landing, but they were unsure what would happen should the flaps be reselected from their current selection of Flap 20 to the required Flap 25. After some discussion they decided it would make little difference because most of the inboard fore flap was missing. The off-duty captain returned to his seat in the passenger cabin where he was able to help reassure some nearby passengers who had become somewhat anxious.

1.1.13 During this time, ATC had cleared NZ 2 to climb to 5000 feet, and then up to 7000 feet to sequence for another landing approach.

1.1.14 As NZ 2 was positioned for another approach the captain reassured the passengers and other crew, advising them of the problem and that they were returning for a normal landing. He said the flaps would be left in the extended position during the taxi after landing.

1.1.15 Normally Flap 30 was selected for landing, but in this case the procedure called for Flap 25 with an approach speed of 25 knots above the reference speed for a Flap 30 approach. Among the considerations for the pilots was that higher speed landings can require an aircraft tyre change afterwards, but they determined the landing speed would be under the threshold necessitating a tyre change.

1.1.16 Flap 25 was selected with only a slight autopilot roll correction noticed. The captain then hand flew NZ 2 for the landing, with no control problems. The captain recalled that he had hand flown the aircraft for a period during the missed approach with Flap 20 selected, and during the departure from Auckland when he felt the bumps. The captain had no control difficulties during those periods either.

1.1.17 The off-duty captain seated in the passenger cabin observed the movement of the flaps following the Flap 25 selection. He said the outboard flaps moved normally to the Flap 25 position, but the inboard flaps remained stationary at Flap 10.

1.1.18 ATC asked the captain of NZ 2 if he needed any assistance or if he was going to declare an emergency. The pilots had determined that the passengers and the aircraft were in no danger, so the first officer advised ATC that no assistance should be necessary and that no emergency was being declared. The first officer also advised ATC that because of the flap problem, the flaps would remain extended during the taxi in after landing.

[3] A go-around procedure when an approach is discontinued.

1.1.19 The first officer advised ATC that the landing should be normal, except that NZ 2 might use more runway because of the higher than usual landing speed. In the event, NZ 2 landed safely without incident having used about the same runway length as for a normal landing, and turned off the runway to the usual taxiway. The aircraft then taxied to the terminal with its flaps extended.

1.1.20 The captain completed the necessary after landing reports and conducted a debriefing with the crew.

1.2 Injuries to persons

1.2.1 No one was injured during the incident.

1.3 Personnel information

1.3.1 The flight crew consisted of a captain, a first officer and a second officer. There were 14 cabin crew onboard.

1.3.2 The captain was aged 58. He held an Airline Transport Pilot Licence and a Class 1 Medical Certificate that was valid normally until 10 September 2002, but the certificate had an extended validity period to 10 March 2003 for multi-crew operations only. He was rated on the aircraft type. He had amassed some 21 400 flying hours, including 2600 hours on the Boeing 747-400 type.

1.3.3 The captain had 6 days off duty before the flight and had started duty at 1945 on 30 August, the evening of the incident.

1.3.4 The first officer was aged 46. She held an Airline Transport Pilot Licence and a Class 1 Medical Certificate that was valid normally until 4 July 2002, but the certificate had an extended validity period to 4 January 2003 for multi-crew operations only. She was rated on the aircraft type. She had amassed some 18 000 flying hours, including 3500 hours on the Boeing 747-400 type.

1.3.5 The first officer had been off duty for 10 days until 24 August 2002. She then had 2 days of simulator training working 6.3 hours each day, followed by 2 days off duty. She then had emergency procedures training for 9 hours on 28 August, followed by a day off duty. She had started duty at 1945 the evening of the incident.

1.3.6 The second officer was aged 34. He held an Airline Transport Pilot Licence and a Class 1 Medical Certificate valid until 28 August 2003. He was rated on the aircraft type. He had amassed some 5668 flying hours, including 623 hours on the Boeing 747-400 type.

1.3.7 The second officer had 8 days off duty before the flight and had started duty at 1945 the evening of the incident.

1.4 Aircraft information

1.4.1 ZK-NBS was a Boeing 747-419, serial number 24 386, line number 756, constructed in the United States in October 1989. The aircraft was fitted with 4 Rolls-Royce RB211-524G engines. The aircraft had been issued a non-terminating Certificate of Airworthiness in the standard category.

1.4.2 At the time of the incident the aircraft had amassed 61 156.8 flying hours and 8393 cycles[4], making it the highest hour and cycle Boeing 747 in the operator's fleet. The aircraft records showed ZK-NBS had been maintained in accordance with its routine maintenance requirements,

[4] A take-off and landing.

as called for by the aircraft manufacturer, and that the last scheduled inspection was a "4A" check completed on 1 August 2002. The aircraft was also subjected to daily inspections.

1.4.3 The most recent inspection of the fore flap assembly was during the last "4A" check. This called for a general visual condition and security inspection of the flap assembly, and an on-wing dimensional inspection of the fore flap flight and centre toggle rollers. The fore flap assembly had been inspected visually in October 2001 during a "C" check, which called for a detailed inspection of the inboard and outboard fore flaps, particularly around the flap track levers and sequencing carriages. In August 2000 a major maintenance "D" check had been completed, when the fore flaps were removed and inspected. The side load and flight load carriage bearings were routinely replaced, and the large roller bearings on the flap carriages were subjected to a detailed inspection.

1.4.4 During the "D" check, the left inboard trailing edge fore flap inner link bearing was replaced. The right inboard fore flap inner link bearing was not replaced and it had remained in service on the aircraft since new. There was no requirement to routinely replace the fore flap links or link bearings, so long as they remained serviceable and met the inspection requirements.

1.4.5 The operator was required to implement each Airworthiness Directive (AD) issued by the aircraft manufacturer's state of registry and manufacture, in this case the Federal Aviation Administration (FAA). The FAA had issued AD 99-05-02 effective 5 April 1999, which applied to ZK-NBS. The AD was issued to prevent the failure of the outboard sequence carriage fitting, which could allow the wing inboard fore flap to separate and penetrate the fuselage. The AD required a one-time detailed visual inspection of the inboard fore flap outboard sequence carriage attachment fitting to detect any loose, missing, or migrated shims and loose fasteners. The means of compliance was by implementation of the Manufacturer's Alert Service Bulletin 747-57A2302 effective 10 April 1997, or its revision effective from 18 June 1998.

1.4.6 In respect of ZK-NBS the operator had complied with the AD by implementing Alert Service Bulletin 747-57A2302 Revision 01, effective 18 June 1998, on 24 August 1998.

1.4.7 The aircraft manufacturer had issued Service Letter 747-SL-57-087-A, effective 31 August 1999. The Service Letter promoted the continued reliability of the inboard trailing edge fore flaps by recommending operators perform the inspection and lubrication procedures detailed in Service Bulletin 747-27-2366 effective on 22 December 1998, which was received by the operator in January 1999. The manufacturer had issued the Service Letter and Service Bulletin because of reports of damage to the fore flap and associated components from skewed operation of the fore flap assembly during flight. Skewed operation could occur when a fore flap sequence carriage was out of phase with the other sequence carriage on a given flap assembly. This may be caused by a worn or broken detent roller, which did not lock in the proper position at the flap track detent.

1.4.8 The operator had evaluated the Service Letter on 28 October 1999 and determined its requirements had been satisfied, because Service Bulletin 747-27-2366 had been complied with and the routine maintenance tasks were incorporated into the routine aircraft maintenance programme.

1.4.9 Revision 1 to Service Bulletin 747-27-2366 was issued on 13 December 2001 and was received by the operator in January 2002. The Service Bulletin requirements were incorporated into the maintenance programme in February 2002. In respect of ZK-NBS the routine maintenance tasks called out in the Service Bulletin had been satisfied on 7 March 2002 and 1 August 2002. The routine maintenance tasks were to be accomplished at intervals not exceeding 6 months, 18 months and 8 years.

1.4.10 Leading edge and trailing edge flaps provided increased lift and a decreased stalling speed for take-off and landing. The trailing edge flaps consisted of an inboard group normally powered by one hydraulic system and an outboard group normally powered by another hydraulic system. A secondary electrical drive was automatically employed if a primary hydraulic drive failed. Opposite side trailing edge flaps were mechanically connected to maintain symmetry. The aircraft trailing edge flap system consisted of inboard and outboard flap groups. Each flap group was made up of fore flap, main flap (mid flap) and aft flap segments (see Figures 1 & 2). The aircraft manufacturer classified only the main flaps as primary structure. Fracture of a fore flap attachment link would not necessarily result in partial or complete loss of the fore flap. Because of the design, it was possible for the fore flap to remain functional for an indeterminate period with a fractured link.

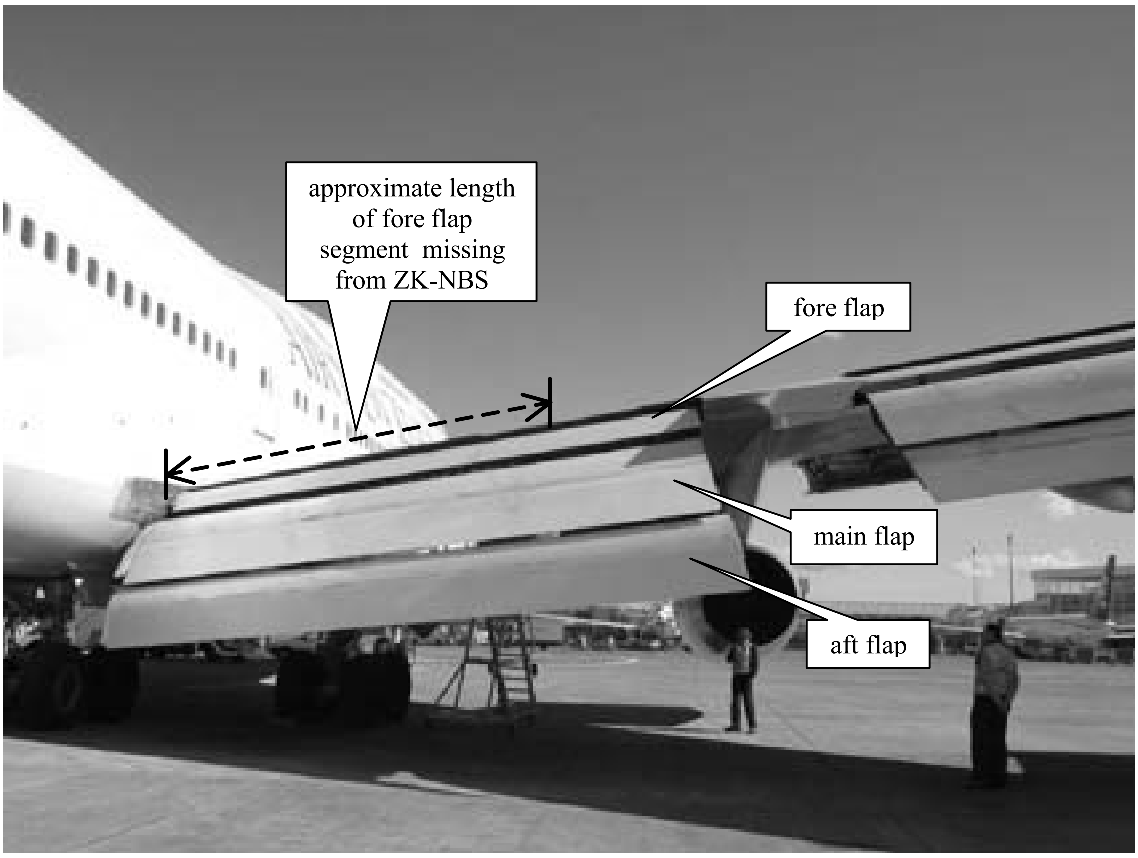
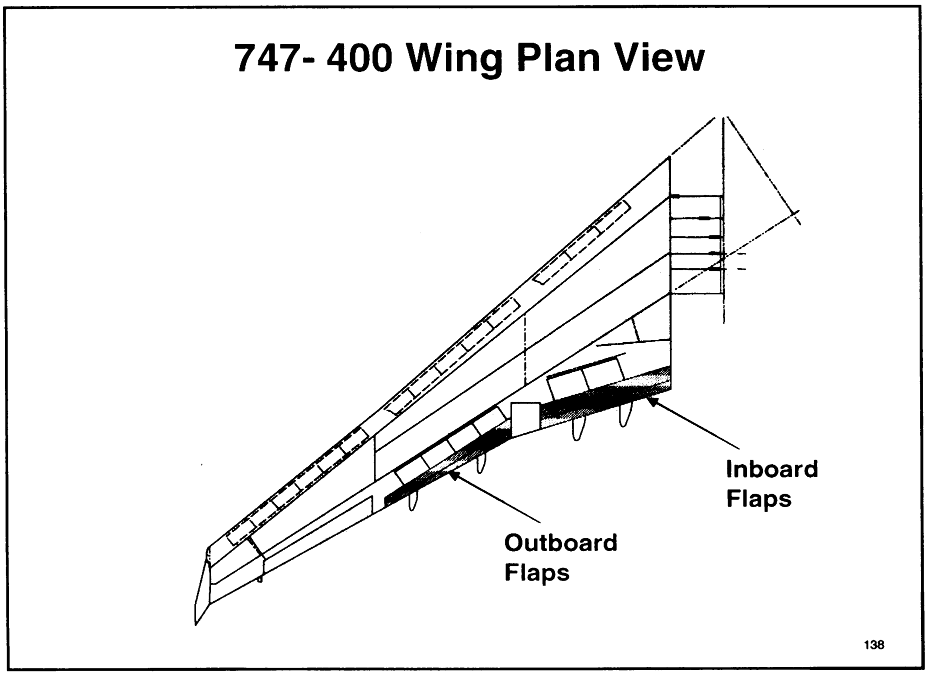


Figure 1
Boeing 747-400 right inboard trailing edge flaps

1.4.11 The trailing edge main flap was attached to, and supported by, 2 flap tracks in the wing by carriages (the moveable attachments between the flap and flap track), which were driven by a ball screw. The fore and aft flaps were attached to and moved with the main flap. The 3 segments were mechanically separate and formed 3 slots as the flaps extended. The flap tracks programmed the change in flap angles as the flap extended. Three fore flap (or mid flap) tracks in the main flap attached to and supported the fore flap. The front of the fore flap was attached to its respective roller carriage assembly by an inner link and an outer fitting (see Figures 2, 3 & 5).

1.4.12 The fore flap inner link contained a swaged self-aligning monoball phenolic bearing, with Teflon lining that provided the lubrication for the inner spherical monoball. The bearing was made from stainless steel material and was press-fitted into its housing in the aluminium alloy link. The bearing edge was peened[5] to prevent it moving in the housing. The bearing was bolted to a clevis[6] on the fore flap carriage assembly. There was no provision to lubricate the phenolic fore flap link bearing, whereas there was provision to grease the fore flap outer fitting bearing.



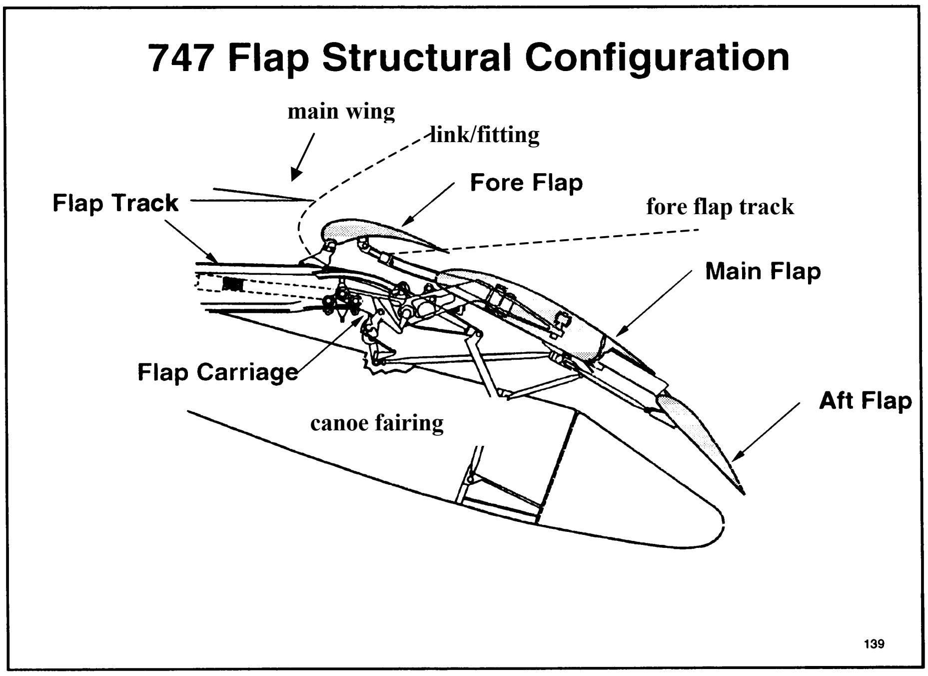


Figure 2
Boeing 747-400 trailing edge flaps

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[5] Shaped or formed by striking.
[6] A U-shaped connection.

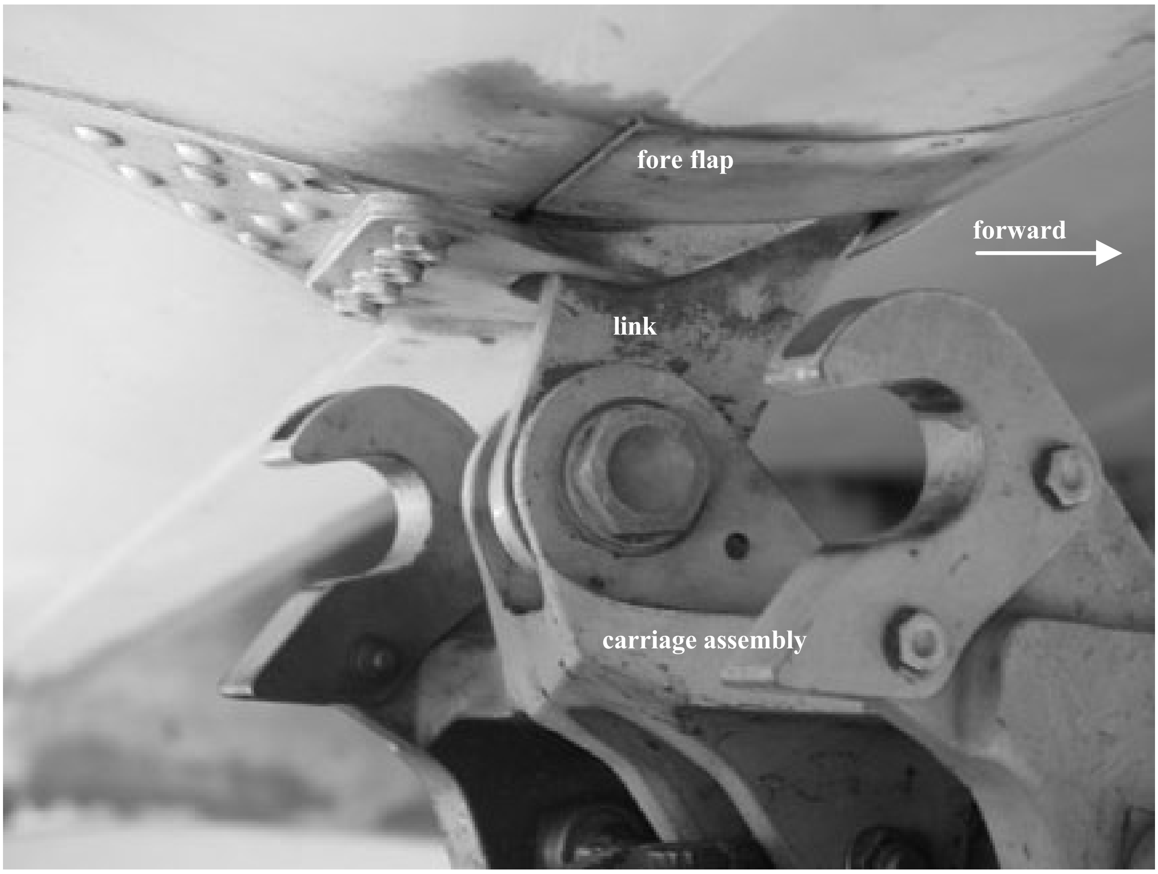

Figure 3
Fore flap and link on another aircraft

1.4.13 When the flaps were extended, they moved aft away from the wing and then down. The flap segments remained together until about 5° of extension (Flap 5), when the fore flap segment stopped moving aft but rotated, and the main flap began to separate from the fore flap. The fore flap rotation was controlled from Flap 5 to Flap 30 by the fore flap tracks. Just past Flap 20, as the main flap continued to extend, the aft flap began to separate from the main flap until Flap 30 when the flaps were fully extended. The reverse occurred during retraction, where the main flap picked up the fore flap and pushed it to its retracted position tucked beneath the aft section of the wing. In its retracted position the fore flap was sheltered from the normal airflow by the wing.

1.4.14 The cockpit flap lever position was transmitted to 3 identical flap control units that sequenced and monitored the flap operation. The flap control units provided trailing edge flap asymmetry protection. If the units detected a flap asymmetry of 1° to 2° between the respective left and right flap systems, the flaps were prevented from extending further, thus protecting the aircraft from an adverse roll or other control difficulties. If a flap asymmetry condition occurred, the pilots would be alerted by a FLAPS DRIVE caution message on the cockpit EICAS display, as they were in this incident. The airspeed limits with the flaps extended were: 280 knots at Flap 1; 260 knots at Flap 5; 240 knots at Flap 10; 230 knots at Flap 20; 205 knots at Flap 25; 180 knots at Flap 30.

1.4.15 The normal flap position indication was a simple bar on the main cockpit EICAS display, which displayed the combined leading edge and trailing edge flap positions when all flap groups were operating normally in the primary mode. If any flap position was abnormal or flap control was in the secondary mode the display expanded to show all flap groups, as it did in this instance.

1.5 Meteorological information

1.5.1 The local meteorological conditions did not contribute to the incident.

1.6 Aids to navigation

1.6.1 Normal.

1.7 Communication

1.7.1 Normal.

1.8 Aerodrome information

1.8.1 The aerodromes used were appropriate and did not contribute to the incident.

1.9 Flight recorders

1.9.1 ZK-NBS was fitted with a Digital Flight Data Recorder (DFDR) recording multiple channels, and a solid state Cockpit Voice Recorder (CVR) recording the last 30 minutes of flight.

1.9.2 The United States National Transportation Safety Board (NTSB) completed a DFDR data dump and secured the CVR unit for the Commission. The NTSB forwarded the unread DFDR data and the CVR unit to the Commission.

1.9.3 The DFDR data were recovered in New Zealand. The CVR was forwarded to the Australian Transport Safety Bureau for data recovery, and the recovered information was returned to the Commission by secure hand for transcribing and analysis should it be necessary for the investigation. In the event, the Commission did not transcribe or analyse the CVR information.

1.9.4 A number of DFDR channels were read, including altitude, airspeed, heading, flap lever position, left and right flap position, control wheel position and vertical and lateral acceleration.

1.9.5 No anomalies or adverse operating conditions were found from the DFDR information. The DFDR information showed that the trailing edge flaps were at Flap 20 for the take-off and departure, and that the inboard trailing edge flaps were at Flap 10 and that the outboard trailing edge flaps were at Flap 25 for the landing at Los Angeles. There was no information that showed when the fore flap had separated. The DFDR information showed that the flaps had been operated within the required airspeed limitations.

1.10 Wreckage and impact information

1.10.1 About 70% of the innermost segment of the right inboard trailing edge fore flap separated from ZK-NBS during the departure from Auckland (see Figure 1). The outermost flap segment was found skewed about 20° and remained attached to the aircraft, being bolted to the outer fore flap carriage by way of its fitting. The inner fore flap link attachment bolt and bearing remained attached to the flap carriage. A fractured end segment of the fore flap link (see Figure 6) was found inside the inner flap track fairing (canoe).

1.10.2 The flap separation caused some minor damage to the aircraft structure near the inner aileron, some fittings and hydraulic tubing. No fluid leaks occurred. There was a minor fuselage skin score just aft of the flaps and a small dent in the leading edge of the right horizontal stabiliser.

1.10.3 The inner and centre main flap load roller arms that supported the fore flap had fractured in overload with the fractured pieces remaining attached to the main flap and fore flap respectively. The 3 main flap load roller arm receptacles were damaged at their leading edges and entranceway to the main flap. The aft flap was undamaged.

1.10.4 Some fishermen found a piece of the inboard fore flap leading edge in the Manukau Harbour, with a segment of its inner main flap load roller arm attached, at about the same time NZ 2 landed at Los Angeles. About 3 metres of fore flap trailing edge honeycomb was also recovered. The corresponding fore flap leading edge segment, which contained the fractured inner link and centre fore flap to main flap load roller arm, was found about 2 weeks later washed up on a beach. An earlier extensive sea and aerial search did not locate the missing flap segment.

1.11 Other damage

1.11.1 After the fore flap pieces separated from NZ 2 they landed in the Manukau Harbour, with no reported injury or property damage.

1.12 Fire

1.12.1 No fire occurred.

1.13 Tests and research

1.13.1 To determine the cause of the fore flap link failure the Commission had Materials Performance Technologies examine and analyse the fractured link pieces, link bearing and securing bolt.

1.13.2 The link failed at either side of the bearing-mounting hole (see Figure 4) where the bearing attached the link and fore flap to the inner fore flap carriage assembly. Significant features were that whereas one side had failed in overload, the area of overload on the other side was less than 25% of the fracture surface, and that a pre-existing stress corrosion crack covered over 75% of the surface (see Figures 6 and 7).

1.13.3 A metallographic section was taken through the link and analysed. The link was made from aluminium alloy and met the required specifications. A hardness test revealed the correct hardness, showing that the link had probably been properly heat-treated and met the required tensile strength. The link was the correct part for the aircraft.

1.13.4 Analysis of the link self-aligning monoball bearing showed it was made from stainless steel material and that it probably met the required specifications. The inner spherical bearing lining was made from Teflon. The bearing was the correct bearing for the link.

1.13.5 The spherical self-aligning monoball bearing showed normal wear from use and vibration over the years. There had been ingress of moisture between the outer bearing and the link and some pitting corrosion had resulted. The small size of the pits suggested the area had not been wet for long periods over the life of the link. Fretting[7] was present in 2 opposing sites, both on the link and the outside of the outer bearing where it fitted in the link. The locations of the fretting damage on the outer bearing indicated that the failure occurred at the edge of the fretted region. Extensive surface cracking was present in the fretted regions on the link. Fretting has a major effect on the initiation of fatigue cracks. Where fretting damage is present, the stress range to cause fatigue damage can be less than 25% of the stress range in the unfretted state. Cyclic stress and the environment controlled the link cracking.

1.13.6 The metallurgist said it was highly unlikely that the link failure occurred from incorrect installation or the incorrect use of the material. Fracture surface "A" (see Figures 4, 6 & 7) was the major failure and it had a number of initiation points along the width of the link, indicating that the loading on the component was even. The fracture sequence was stress corrosion cracking, followed by corrosion fatigue, followed by fatigue and then overload.

[7] To damage, wear or consume by hammering, gnawing or rubbing; to irritate.

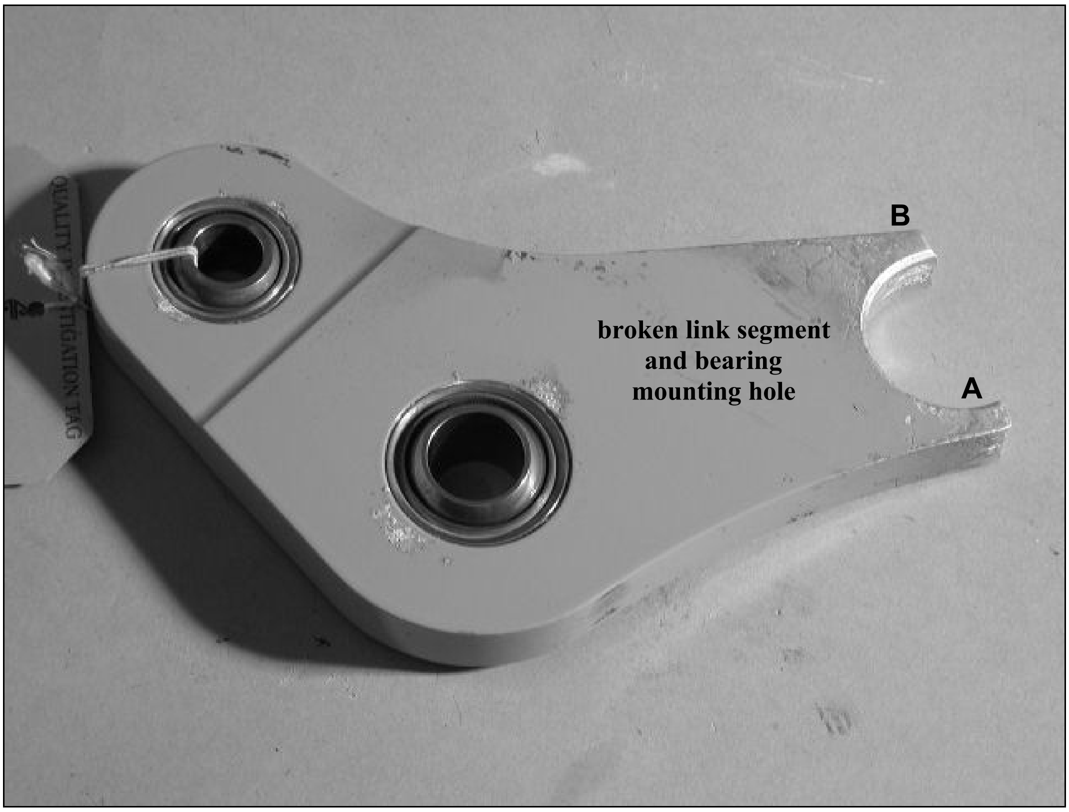

Figure 4
Failed fore flap link from ZK-NBS

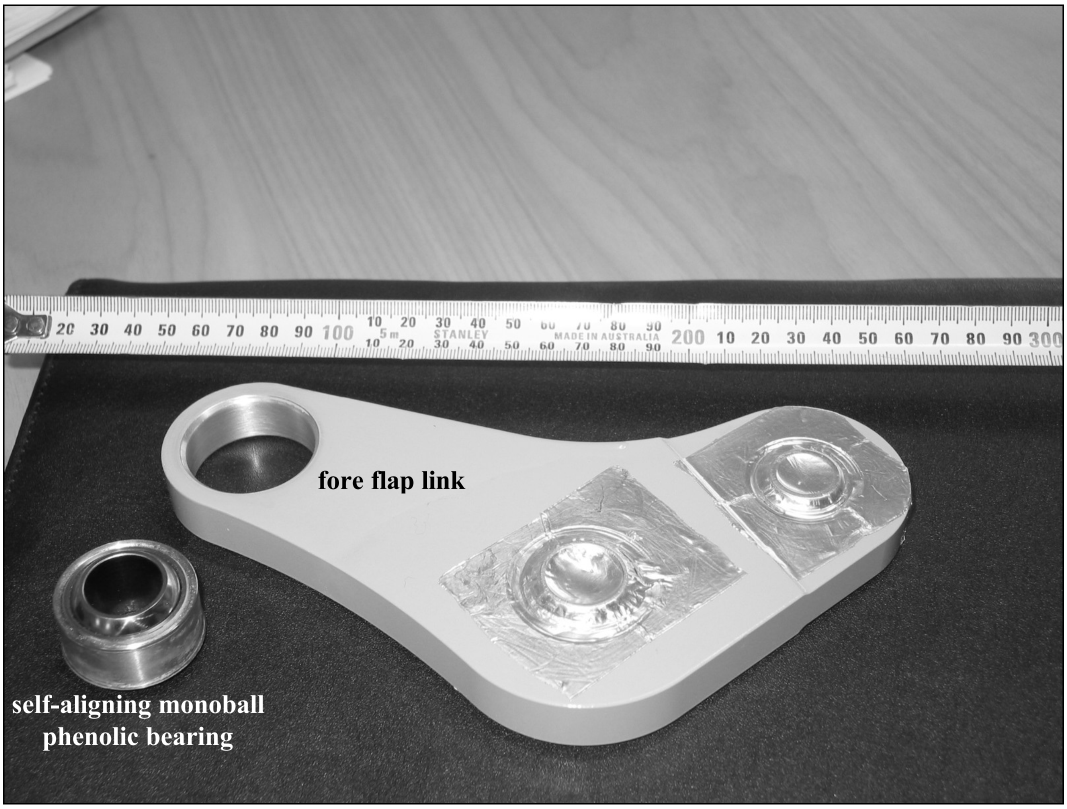

Figure 5
Fore flap link with bearing removed, from another aircraft

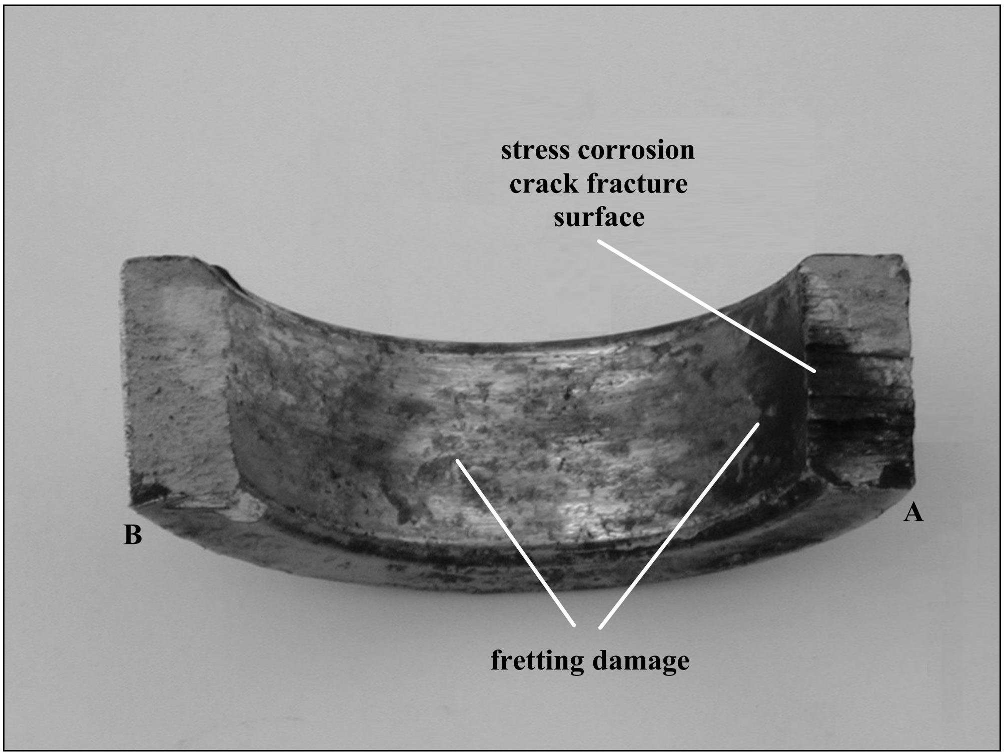

Figure 6
Failed fore flap link piece

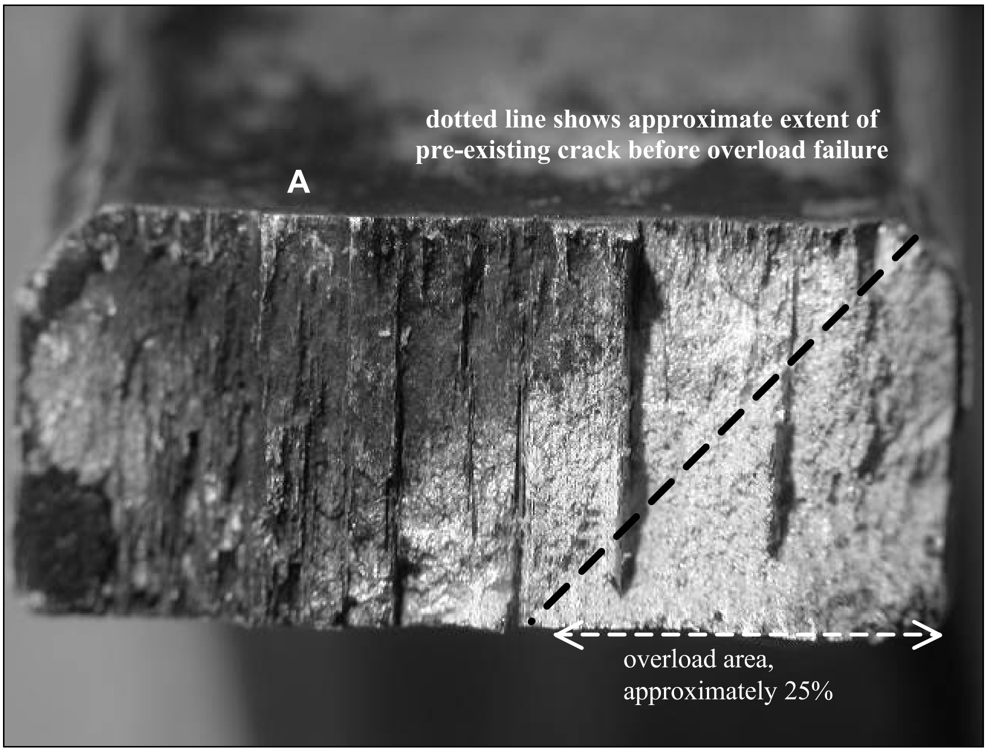

Figure 7
Failed link piece fracture surface A

1.13.7 The metallurgist said the aluminium alloy used to manufacture the link is prone to stress corrosion cracking and that these types of failures are not unknown. If the environment and the applied stress were present from when the bearing was installed, and both were sufficient to cause stress corrosion cracking, the cracking would probably have occurred in a few months of operation rather than over the life of the aircraft. The time period suggested the conditions became worse with time and the crack finally propagated in fatigue. The fracture surfaces were not heavily polished, also indicating that the cracking had not been present for a long period.

1.13.8 The stress corrosion cracking in fracture surface "A" spread across the entire section and the metallurgist said it was highly probable the cracking started as fretting corrosion fatigue cracks. A significant amount of fretting debris was present in the area indicating that fretting had occurred and that fretting damage was present in the area.

1.13.9 An initiation process similar to that of fracture "A" probably caused the cracking at the bore side of fracture surface "B" (see Figures 4 & 6). The cracks were predominately caused by fretting fatigue.

1.13.10 The metallurgist said it was probable the conditions became worse because of bearing wear. The bearing condition would have increased the applied loading to the link because of increased friction and vibration. Movement between the outer bearing shell and the link would have enhanced moisture ingress to the area and accentuated the corrosion.

1.13.11 The metallurgist said it was unlikely that any damage to the link would have been visible unless the bearing was first removed from the link.

1.14 Organisational and management information

1.14.1 Following the fore flap separation the operator started a programme for an immediate special visual inspection of trailing edge flap assemblies on its Boeing 747 fleet. The inspection included checking for security, corrosion, cracking or delamination. No other faults were detected.

1.14.2 The special inspection was followed by non-destructive eddy current tests around the monoball bearing areas of the fore flap links and fittings on its Boeing 747 fleet. The tests were completed within 5 days of the incident and resulted in the replacement of one fitting because of suspected superficial corrosion on the link face between the bearing and its housing.

1.14.3 The operator also put a fore flap link (with bearings fitted) replacement programme in place, which resulted in its Boeing 747 fleet having the inboard fore flap links replaced by the end of September 2002.

1.14.4 The aircraft manufacturer requested the operator send it all the inboard fore flap attachment fittings removed from its fleet after the link replacement programme was complete. The manufacturer visually inspected each lower bearing bore and consequently selected 4 fittings for further review using dye penetrant and eddy current methods. All 4 fittings showed significant amounts of corrosion pitting and intergranular corrosion cracking in the lower bearing bores.

1.14.5 Until mid 2000, the aircraft manufacturer had communicated the experiences of other Boeing 747 operators to all operators of its aircraft by its In-Service Activity Reports (ISAR) in paper form. Since that time a Fleet Team Digest (FTD), accessed through the manufacturer's website, superseded the ISARs.

1.14.6 The first reported fracture of a Boeing 747-400 inboard fore flap link, which resulted in a partial inboard fore flap separation, occurred on 7 June 1997 when the subject aircraft was on approach to land. The aircraft landed without incident, but a post landing inspection showed about 60% of the fore flap was missing. This incident involved a different operator but was similar to that experienced by ZK-NBS. The aircraft manufacturer reported the incident in ISAR 97-14-5755-14, which said that since this was the first reported fracture of an inboard fore flap link assembly no further investigation was planned at that time, but that fleet activity would be monitored.

1.14.7 Two further instances of fore flap link fractures were reported, but no parts separated from the aircraft. The last instance was in May 2002, which was still under investigation by the aircraft manufacturer at the time of the ZK-NBS incident. The manufacturer completed a metallurgical analysis of the fractured fittings from the 3 earlier events and found indications of stress corrosion cracking at the bore surface for each of the fittings. Consequently, the manufacturer initiated a design improvement programme in June 2002 to enhance the fitting's corrosion resistance.

2 Analysis

2.1 Flight NZ 2 started as a routine event, under the control of a qualified, experienced and adequately rested crew. The aircraft had been properly dispatched and there were no known aircraft defects or problems that could affect the flight.

2.2 NZ 2 was configured correctly for take-off. The aircraft took off normally, in darkness, and started a left climbing turn a short time later. During the turn, with the flaps still selected normally to Flap 20 and with the flap airspeed limitations being observed, the right inboard trailing edge fore flap link attachment failed. Consequently, with the left main attachment for the fore flap broken, the air loads on the fore flap were such that a substantial segment of the fore flap separated from the aircraft. The outboard fitting attachment and about 30% of the fore flap, outboard from the attachment, remained secure on the aircraft.

2.3 Some further minor damage to the aircraft occurred, but its flight characteristics were unaffected and the crew experienced no control abnormalities. Apart from the slight unexpected bumps, thought to be some turbulence, the crew was unaware of anything untoward. There were no warnings and no performance loss to indicate to the crew the nature of the problem. Because it was dark it was not possible for any of the cabin crew or passengers to have observed the flap separation. The flaps retracted normally and once they were in the retracted position the fore flaps were hidden from view beneath the wing. The flight continued with the aircraft performing normally. Consequently, the crew remained unaware of the problem until flaps were selected some 12 hours later during the landing approach at Los Angeles.

2.4 Once the crew discovered the fore flap loss the actions they took at Los Angeles were appropriate. The safety of the aircraft and its occupants was maintained by the professionalism of the crew and from the assistance offered by the off-duty pilot.

2.5 The aircraft manufacturer had not classified the fore flaps as primary structure because it had determined that the loss of a fore flap would not compromise the safety of the aircraft. The flight of NZ 2 bore testimony to this, but the safety of people and property beneath the departure and approach path of the aircraft could be compromised by a fore flap separation. In this instance the fore flap segments landed harmlessly in the Manukau Harbour, but the situation could have been much worse had the separation occurred over a populous area.

2.6 The fore flap link failed because a large pre-existing crack had grown to a critical size. The crack covered about 75% of the cross section of the link in the area housing the self-aligning monoball end bearing.

2.7 The pre-existing crack had grown in size because of fatigue crack propagation before the failure. The link loading would have occurred because of normal flap vibration combined with a cyclic load each time the flaps were operated. Once the crack began, its propagation was probably relatively rapid and probably occurred over a period of a few flights only.

2.8 The majority of the cracking occurred because of stress corrosion cracking followed by corrosion fatigue. The rate of cracking was unknown, but stress corrosion cracking can increase rapidly. The crack faces were not heavily polished, suggesting that the crack had propagated in a relatively short period of time, weeks rather than months or years.

2.9 The crack probably started because of fretting and corrosion between the outer stainless steel self-aligning monoball bearing shell and the aluminium alloy link. The fretting will have exacerbated the ingress of moisture into the gap between the bearing shell and the link. The fretting damage that was evident probably formed over a number of years and was probably accentuated by bearing wear that had also occurred over the same time.

2.10 The damage to the link would not have been detectable before a significant crack had started and grown, unless the bearing was removed from the link. There was no requirement in place to remove or routinely replace the link bearing or the link itself. The required link inspections would not be expected to detect the cracking found. The operator had carried out all the necessary inspections on the fore flap assembly and was unaware that a pre-existing crack in the link had grown to a critical size.

2.11 The operator's actions immediately following the fore flap separation were appropriate to ensure the safety of its Boeing 747 fleet and to potentially prevent further fore flap separations.

2.12 The aircraft manufacturer's action in reporting and investigating the previous Boeing 747-400 fore flap link failures and initiating an engineering design improvement was appropriate.

2.13 Because of the similar nature of all the link failures with evidence of stress corrosion cracking, including that found on some of the intact links removed from the operator's other aircraft, the manufacturer's design improvement was needed to overcome the limitations of the fore flap link attachments.

3 Findings

Findings and safety recommendations are listed in order of development and not in order of priority.

3.1 The aircraft records showed ZK-NBS had been properly maintained in accordance with its maintenance requirements.

3.2 The fore flap separation resulted from the failure of its inboard link attachment.

3.3 The loss of the fore flap did not compromise the safety of the aircraft or its occupants.

3.4 The inboard link attachment had a pre-existing stress corrosion crack that had grown to a critical length before, or during, the departure.

3.5 The crack started because of fretting and corrosion between the outer shell of the self-aligning monoball bearing and the link.

3.6 The inspection procedures called for by the aircraft manufacturer up to the time of the link failure were not sufficient to ensure that any pre-existing cracks would be detected.

3.7 The actions taken by the operator immediately following the incident ensured the ongoing safety of its Boeing 747 fleet from further inboard fore flap separations.

3.8 The aircraft manufacturer's redesign of the fore flap attachment fittings to enhance their corrosion resistance should provide a long-term solution to prevent further fore flap link failures.

3.9 There were no operational factors identified that could have contributed to the fore flap separation.

3.10 The crew acted professionally and took the appropriate action after discovering the loss of the fore flap.

4 Safety Actions

4.1 As a result of the aircraft manufacturer's investigation into the previous 3 fore flap attachment link failures, the manufacturer initiated a design improvement programme in June 2002 to enhance the fore flap fitting's corrosion resistance. The design improvement has been completed, with the revised fittings scheduled for installation on production aircraft starting at line position 1335 (fourth quarter 2003 delivery). The fitting design improvements are as follows:

- aluminium alloy fitting material changed from 2024-T351 to 7075-T7351 for improved resistance to stress corrosion (i.e. improved stress corrosion threshold)
- increased net section in the lower lug to reduce the overall stress levels
- grain direction controlled
- fitting and all bearing holes shot peened
- bearing and outer race cadmium plated
- changed bearing installation from wet installation with primer to a shrink fit installation wet with BMS 5-95 sealant.

The manufacturer expects to provide recommended operator action in the third quarter of 2003 to coincide with the production incorporation of the changed fitting assembly.

4.2 In December 2002 the aircraft manufacturer issued a FTD, 747-400-FTD-57-02004, advising operators about the partial fore flap loss involving NZ 2. The FTD advised that the manufacturer had started a design improvement and that interim action was pending. The manufacturer advised it will require inspections of the fore flap links to ensure their integrity until the remanufactured components are available. The FTD detailed the operator action to provide maximum inboard and outboard trailing edge fore flap system reliability. The operator of NZ 2 had already taken the action recommended when the manufacturer issued the FTD. The manufacturer's communication to Boeing 747 operators providing ongoing status on the issue will be through its FTD articles.

4.3 Because of the aircraft manufacturer's action and design improvement of the fore flap attachments fittings, which should provide the long term solution necessary to prevent further failures, no safety recommendations were considered necessary.

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Hon. W P Jeffries
Chief Commissioner

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Transport Accident Investigation Commission
P O Box 10-323, Wellington, New Zealand
Phone +64 4 473 3112   Fax +64 4 499 1510
E-mail: reports@taic.org.nz   Website: www.taic.org.nz

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