Hidden hazard

PHOTO: AAP

A patch on a China Airlines jet might have concealed a fatal flaw that killed 225 people.

Martin Aubury reports.

ON MAY 25, 2002, at 1528 local time, China Airlines Flight CI 611, a Boeing 747-200 (B18255), crashed soon after takeoff from Chiang Kai-Shek International Airport, Taipei, Taiwan, en route to Hong Kong.

Radar data show the aircraft broke up inflight at 35,000 feet. All 209 passengers and 16 crew members were killed.

The Aviation Safety Council of Taiwan (ASC) and the US National Transportation Safety Board have mounted a huge effort to recover the wreckage from the depths of the Taiwan Straits in a bid to find clues to the cause of the accident. The ASC recently reported interim findings.

Investigators now know that the fuselage suffered an explosive decompression, probably caused by fatigue failure of a patch that had been applied 22 years earlier.

The ASC is not yet certain the old repair is to blame, but has eliminated other likely causes of the crash. And it is urging national airworthiness authorities to ensure that transport category aircraft with fuselage repairs are inspected immediately for any damage hidden by the work.

Old repairs The crash of Flight CI 611 drives home the fact that repairs that are structurally sound and airworthy when installed often deteriorate. And the deterioration, as in the case of the aircraft operating Flight 611, is usually hidden beneath the repair.

The damage to the aircraft in 1980 did not seem very serious. During landing, the plane scraped the bottom of its aft fuselage, scratching the belly skin over three metres just forward of the rear pressure bulkhead, and bending some brackets inside the fuselage. The damage was easily repaired, mainly with an external skin doubler patch, spanning seven frames and four stringers.

For the next 22 years the skin beneath the patch fatigued, cracked and corroded undetected beneath the patch.

Much of the wreckage of Flight 611 has been retrieved and thorough investigation has, according to the ASC, "found no evidence [of] fire, smoke, explosives, external forces and in any security related matters relevant to this accident".

Out of more than 1,400 pieces of wreckage, investigators have focused on item #640. It is the part of the fuselage damaged and repaired in 1980, a large piece of skin panel from the very bottom of the fuselage between Body Station STA 1920 (inches) and STA 2181, and from Stringer 49 left to Stringer 23 right. On the inside of the skin, most of the stringers are still attached. On the outside of the skin there is a repair doubler patch from STA 2060 to STA 2180 and spanning from just above stringer S-49L to above S-51R. Rivets through the doubler, skin and stringers join them together.

Along the lengthwise edge of item #640 just above S-49L there are several fatigue cracks, the longest about 380mm. They are underneath the repair doubler and follow the outermost row of rivets. These cracks evidently existed before the fatal accident. The rest of the periphery of this piece of skin was torn from the adjacent structure during the break-up.

When investigators carefully removed all rivets and separated the repair patch from the skin, they found scratches on the skin "almost everywhere". The scratches were consistent with having occurred during the 1980 tail strike. There was evidence of "rework sanding marks" but the rework did not completely remove the tail strike scratches.

Item #640 debris that contains the patch displays:

• many scratches on the fuselage skin beneath the repair patch, metal rubbing and widespread fatigue crack growth

• fatigue cracks at multiple sites in the skin, mainly tracing the scratches where they correspond to the outermost row of rivets through the patch

• 1,765mm (total end-to-end length) of multiple site fatigue cracks, covered by the patch, including a critical 645mm length in the fuselage skin below one edge of the patch. 383mm of this crack is continuous and penetrates the skin.

Durability Experts on aircraft structural fatigue have long been concerned about the durability of old repairs on old aircraft. Steve Swift, writing in the spring 1996 edition of *Flight Safety Australia*, explained why.

Some think that repairing damaged skin with a doubler patch inherently increases the structural strength – that twice the thickness makes the area twice as strong. Not so. The weakness lies not in the repair patch but in the underlying skin, particularly at the outermost row of attachment fasteners. Here load must transfer from the skin into the patch, and stresses are dangerously concentrated. The thicker the patch, the sharper the stress concentration, which is why Swift debunked the engineer's adage, "if it's big and strong, you can't go wrong".

In fact, a strong repair can be too stiff and act as a stress raiser that seriously reduces the durability of the repair and cuts the fatigue life of the underlying structure.

With a conventional external patch repair, any cracks that happen are likely to be obscured by the patch. There are ways to make cracks more obvious – by patching internally, for example. Or an external patch can be designed with scalloped edges so cracks are visible between the scalloped "fingers" of the patch before they become too long. Damage-tolerant repairs are relatively recent innovations, and the legacy and hazards of old, crude repairs will remain for some time yet.

Repair failures Fatigue failures of repairs are not uncommon. The world's worst single aircraft accident happened in 1985 when the rear pressure bulkhead of a Japan Airlines Boeing 747 failed because of faulty repairs. The bulkhead had been damaged in a tail scrape seven years earlier. The poorly repaired structure fatigue went undetected. When it ruptured, a portion of the plane's tail was blown away. Forty minutes later, the aircraft crashed, killing 524 people.

In 1988, an Aloha Airlines B737 lost much of its fuselage, heightening concerns about repair durability. The Aloha accident was due to a combination of faulty design, faulty manufacture, faulty maintenance and faulty repair.

In the aftermath of the accident, investigations found no abnormal maintenance practices at Aloha. This galvanised aircraft manufacturers, airlines and regulators to acknowledge that:

• Undue reliance was placed on maintenance to counter design and production defects.

• Too few safety modifications were installed unless legally enforced by an airworthiness directive.

• Corrosion was far too common.

• Repairs were made without proper regard to durability.

The aviation industry became determined to fix these problems. See "Lesson from Aloha", *BASI Journal*, June 1992, at http://www.iasa.com.au/folders/Safety_Issues/others/lessonsfromaloha.html

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Reconstruction Investigators piece together fragments of Flight 611.

Reassessment Concerning repairs, the Aloha article observed that: "Every aircraft suffers cracks, corrosion and occasional scrapes with service vehicles; and it all gets patched up. A hundred patches on an aircraft is not unusual. Too often they are riveted on in a hurry, with dubious engineering and dubious records. Every one has got to be found, inspected, evaluated and if necessary replaced. It is a huge task and will take years."

In 1991, the Federal Aviation Administration issued Advisory Circular 25.1529.1, Instructions for Continued Airworthiness of Structural Repairs on Transport Airplanes.

But after that, the industry lost its zeal and the reassessment of existing repairs got bogged down in legalistic arguments over how to make the work compulsory.

Eventually, in 2000, reassessment was enforced in the USA, not through an Airworthiness Directive but by amendments to operational rules Parts 91, 121, 125 and 129. Effectively the FAA told operators of specific airplane models that they could not fly unless they put in place procedures to reassess the durability of existing fuselage repairs.

FAA Advisory Circular 120.73, Damage Tolerance Assessment of Repairs to Pressurized Fuselages, gave guidance and in Australia AD/GENERAL/82, Repair Assessment of Pressurised Fuselages, applies the same requirements.

By 2001, operators had to have repair assessment guidelines in their maintenance programs. For old aircraft, this was when assessments began, as operators hunted the patches down. This was done for the Boeing 747 operating Flight 611. However, phase-in of the program meant that work on the China Airlines aircraft was not due until last November – six months and 225 lives too late.

The challenge now for the aviation industry is to learn the lessons from CI 611 by pinpointing deteriorating repairs and fixing them before they become lethal.

Pervasive hazard A formal requirement for reassessment of repairs applies only to a limited range of old transport category aircraft and only to their pressurised fuselages. And, as a direct result of the CI 611 accident, the FAA and CASA issued directives to inspect tail strike repairs only on Boeing 747s, not other types similarly at risk.

However, maintenance organisations would be wise to heed the ASC warning and check the integrity of all fuselage repairs. And they should not neglect wings. In one case, an Australian Lockheed L-188 Electra barely made it to safety when a repaired wing plank ruptured in-flight.

Be suspicious of all structural repairs. Be especially concerned about patches that are unusually old, large or thick. And be alert for small cracks emerging from under the edge of a patch repair.

Look for signs of loose or working rivets, and be wary of stains streaking from under a patch. They might be the signature of pressure or fluid leaks. And take any available opportunity to check internally for cracks hidden under external repairs.

As the ASC observes: "An improperly treated scratch on the aircraft pressure vessel skin, especially if covered under a repair doubler, could be hidden damage that might develop into fatigue cracking, eventually causing structural failure."

See http://www.asc.gov.tw for the Aviation Safety Council's interim factual findings on the crash of Flight CI 611.

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