National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: April 8, 2003

In reply refer to: A-03-07 through -10

Honorable Marion C. Blakey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On May 25, 2002, China Airlines flight CI-611, a Boeing 747-200 (B18255), crashed in the Taiwan Straits near the northern end of the Penghu Islands, Taiwan. Radar data indicate that the airplane experienced an in-flight structural breakup at about 35,000 feet. The airplane was on a scheduled passenger flight from Chiang Kai Shek International Airport, Taipei, Taiwan, to Chek Lap Kok Airport (Hong Kong International Airport), Hong Kong, China. All 225 occupants were killed.

The National Transportation Safety Board is participating in the investigation of this accident, which is being conducted by the Aviation Safety Council (ASC) of Taiwan. The investigation is not yet complete but, based on the information collected to date, the Safety Board has identified a safety issue that should be addressed.

Background

The accident airplane was delivered new to China Airlines on July 16, 1979. Records indicate that on February 7, 1980, the airplane experienced a tailstrike while landing in Hong Kong. Maintenance records stated that the tailstrike caused "serious abrasion damage" to the belly skin of the aft fuselage section from fuselage station (FS) 2080 to 2160 and from FS 2578 to 2638. According to maintenance records, after first installing a temporary repair, China Airlines accomplished a permanent repair on May 25, 1980, by installing two external aluminum patches, known as doublers, from FS 2060 to 2180 and from FS 2598 to 2658,[1] in accordance with China Airlines engineering recommendations and the Boeing Structural Repair Manual (SRM). However, the engineering recommendations applied only to the temporary repair. To date, China Airlines has not provided investigators with any detailed repair

[1] Two additional doublers were also installed on the aircraft but were not mentioned in the maintenance records—one between FS 2180 and 2240 and the other between FS 2484 and 2598.

documentation (such as work cards or inspector signoffs) for the permanent repair. At the time of the accident, the airplane had accumulated approximately 20,631 cycles since the repair and a total of 64,810 hours and 21,398 cycles since new.

The recovered wreckage from the accident airplane included the repair doubler installed between FS 2060 and 2180. The doubler, which was about 120 inches long, 22 inches wide, and 0.100 inch thick, was installed over the original fuselage belly skin between stringers S-49L and S-51R. Although, as noted above, maintenance records indicate that the repair was conducted in accordance with the Boeing SRM, several discrepancies were noted. Specifically, the Boeing SRM required that the damaged skin be removed before installation of the doubler. However, the damaged skin was not removed; the fuselage skin underneath the doubler exhibited severe longitudinal scratching. Some of the scratching was located just outside the left perimeter of the repair rivets but was still hidden under the outer edge of the doubler. Further, most of the rivets attaching the doubler to the fuselage skin were overdriven, and some of the parts used in the repair did not meet the applicable material specifications.

Metallurgical examination of the recovered wreckage revealed a region of fatigue cracking with multiple-site fatigue damage (MSD)[2] extending for about 93 inches under the left edge of the doubler; the fatigue cracks in this region originated at the unremoved scratching just outside of the rivet line and propagated completely through the thickness of the skin in many areas within the fatigue region (see figure 1).[3] The fatigue region also contained individual fatigue cracks that were linked by quasi-stable crack growth, resulting in a single 93-inch-long crack. Almost all[4] of the fatigue cracking was located underneath the doubler and would not have been visible from the exterior of the airplane.

[2] MSD is a series of individual fatigue cracks oriented in the same direction. MSD is typically found along rivet lines, with the fatigue cracks emanating from some or all of the rivet holes, but can also be associated with scratches or other types of damage containing multiple stress points giving rise to multiple fatigue cracks.

[3] The fuselage skin was also fractured underneath the forward and aft edges of the doubler, but these fractures did not show evidence of fatigue cracking. Rather, the fractures were consistent with overload failure.

[4] Only 5 inches of the crack extended outside the forward edge of the doubler.

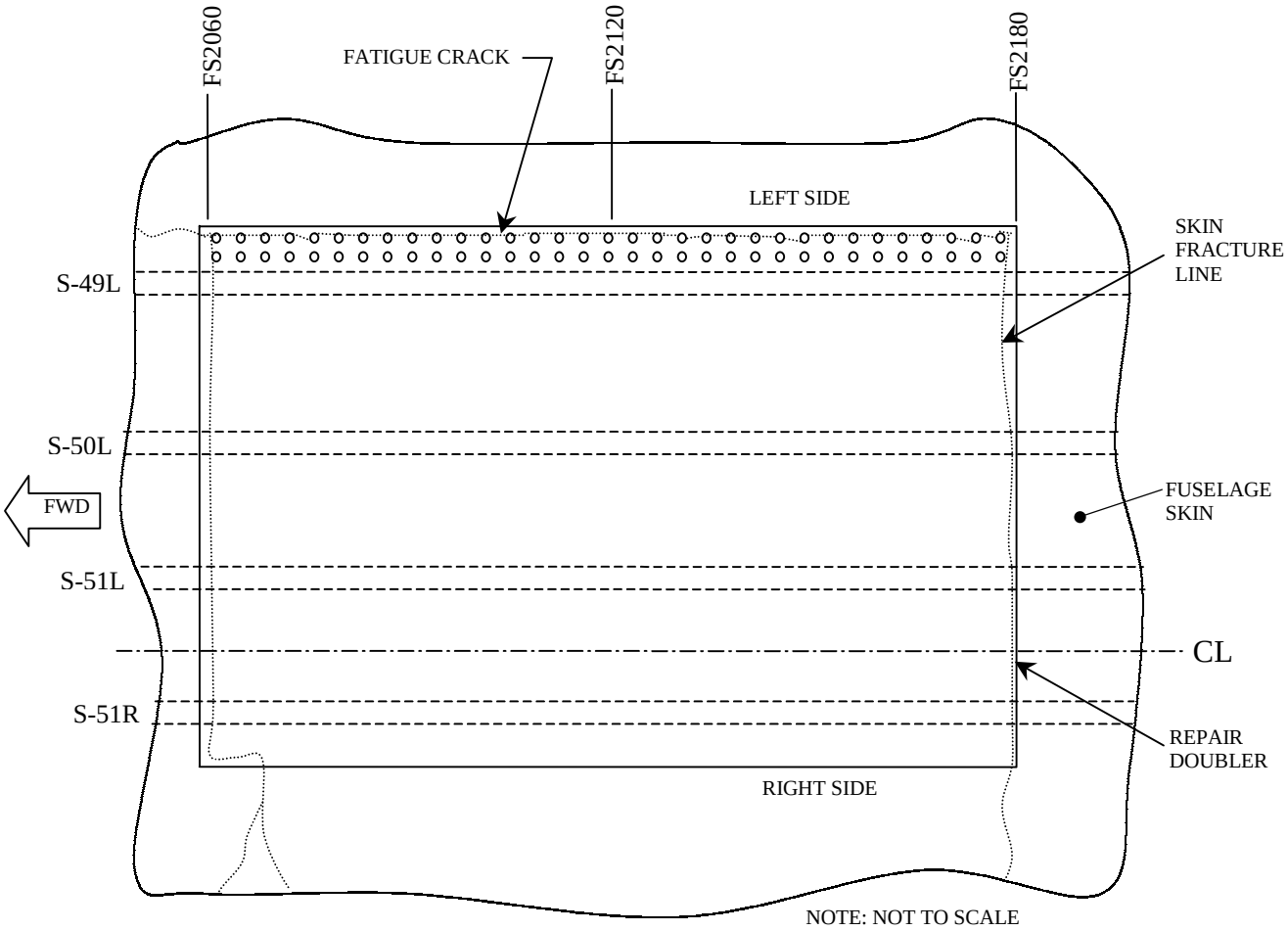

Figure 1. Detail of the China Airlines 747-200 repair doubler
(View looking up at bottom of aft fuselage)

Safety Hazards Posed by Hidden Damage

The investigation of the China Airlines flight CI-611 accident is still ongoing and the ASC has not yet determined whether the fatigue crack under the left side of the doubler caused or contributed to the in-flight structural breakup. Nonetheless, the hidden damage and associated MSD and fatigue fractures found on the accident airplane raise serious safety concerns because of the possibility that similar hidden damage could exist on other transport-category airplanes. The Safety Board considers the immediate identification and repair of any such hidden damage to be crucial because fatigue cracking in the pressurized compartments of an airplane (known as the pressure vessel) could lead to a catastrophic structural failure.

The Safety Board notes that Boeing has issued Service Bulletin (SB) 747-53A2489, dated November 26, 2002, calling for the removal of certain doublers

on 747 airplanes if the doubler was installed to repair tailstrike damage or if the reason for repair cannot be determined through maintenance records. The SB calls for an assessment of the underlying fuselage skin for scratching damage after the doubler has been removed; if any such scratching damage is found, the damage must be repaired in accordance with the Boeing SRM.

If the doubler cannot be removed within the time period specified in the SB, the SB specifies that the operators should perform repetitive inspections around the edges of the doubler until the doubler is removed and the skin can be assessed. If the inspections reveal any cracks, the doubler must immediately be removed and the damage repaired in accordance with the Boeing SRM. If no cracking is found, repetitive inspections must continue until the doubler is removed and the skin can be assessed. For the repetitive inspections, the SB specifies the use of either a newly developed mid-frequency eddy current technique performed internally or, in the case of repair doublers of 20 inches or less, an external visual inspection.

On January 24, 2003, the Federal Aviation Administration (FAA) issued an airworthiness directive (AD) requiring inspections and corrective actions substantially similar to those described in SB 747-53A2489. The Safety Board supports these actions but is concerned that the scope of the SB and AD may be too narrow in that repairs of damage other than tailstrike damage, and to airplanes other than 747s, could also hide damage that could lead to fatigue fracturing and structural failure.

Additional evaluation and analysis is needed before adequate criteria can be established to identify all types of pressure vessel repairs to transport-category airplanes that could be hiding damage—either from the original incident or introduced during the repair process—and that might be susceptible to MSD and fatigue cracking. The Safety Board anticipates that as part of such an evaluation and analysis, the size of the repair would be considered a significant factor. The Board recognizes that the type of airplane being considered and other factors might affect the level of risk posed by a particular size repair. However, in general, repairs that are of sufficient size to hide significant longitudinal or circumferential damage should be evaluated.

With regard to the age of the repair, the Safety Board notes that the repair on the accident airplane had accumulated a significant number of cycles (approximately 20,631) since the repair. Striation estimates performed in connection with this accident investigation revealed that the number of cycles it took for the multiple origin points of the fatigue fracture to propagate through the thickness to the exterior of the fuselage skin ranged from approximately 2,400 to approximately 11,000 cycles. However, it is unknown exactly when the crack growth began and, therefore, it is unknown how soon after the repair the first signs of cracking would have been detectable. The Board is aware of other instances in which fatigue cracking originating at damage hidden by a repair may not have begun until long after the repair was accomplished, but the cracking propagated to failure within as few as approximately 4,000 cycles after it began.[5] Therefore, the age

[5] A January 25, 1987, rapid decompression on a United Airlines 727, and a December 26, 1988, rapid decompression on an Eastern Air Lines 727, were both attributed to fatigue fractures originating at scratch

of a repair may not be a significant factor in establishing appropriate criteria, and there may be other relevant considerations that should be taken into account.

Accordingly, the Safety Board believes that the FAA should establish appropriate criteria (taking into account the size of the repair and other relevant considerations) to identify those pressure vessel repairs to transport-category airplanes that could be hiding damage that, if not addressed, may lead to MSD and fatigue cracking and could result in structural failure of the airplane.

Determination of an appropriate inspection technique may involve consideration of several factors. As already noted, because almost all of the MSD and fatigue fracture on the accident airplane were located underneath the repair doubler, they would not have been detectable from an external visual inspection. Further, because the cracking initiated from the external surface of the fuselage skin and propagated inward, the damage also would not have been visually detectable from inside the airplane until the cracking had propagated all the way through the fuselage skin. Therefore, it is apparent that visual inspections, by themselves, are not sufficient to detect MSD or fatigue cracking of this type. Moreover, standard nondestructive inspection (NDI) methods are not able to consistently detect cracks through a doubler, nor are standard eddy current methods able to detect cracks on the reverse side of the material being inspected that have not propagated through the entire thickness of the fuselage skin. Therefore, standard methods will not detect all potentially hazardous cracks. The Safety Board is aware that, as a result of this investigation, a new NDI method using mid-frequency eddy current has been developed (and others are being explored) that may be able to detect cracks of a certain size on the opposite face of the material being inspected. However, in areas of the repair that are not accessible to the new NDI technique, the doubler should be removed so that direct examination of the underlying skin can be performed.

Regarding the determination of an appropriate repetitive inspection interval for those cases in which NDI is appropriate, the Safety Board notes that, when failure mechanisms are known and clearly defined, standard industry practice ensures a damage-tolerant design by establishing a safety margin that allows for two complete inspection cycles before the predicted failure time.[6] Thus, even if one inspection is

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or score marks introduced in the course of an earlier repair. In the first case, the repair was 23 years old and in the second case, the date of the repair could not be determined. But, in both cases, striation counts showed that the cracking began approximately 4,000 cycles before the structural failure. As a result of these two incidents the Safety Board issued Safety Recommendation A-89-79, which asked the FAA to issue a maintenance bulletin informing maintenance personnel "about the serious consequences of minor scratches on pressurized fuselage skin." On September 10, 1990, Safety Recommendation A-89-79 was classified "Closed—Acceptable Alternate Action" after the FAA issued an action notice and an airworthiness alert and several aviation maintenance organizations published articles addressing this subject.

[6] According to the FAA's *Damage Tolerance Assessment Handbook, Volume I*, issued in February 1999, "damage tolerance refers to the ability of the design to prevent structural cracks from precipitating catastrophic fracture when the airframe is subjected to flight or ground loads. Transport category airframe structure is generally made damage tolerant by means of redundant ('fail safe') designs for which the inspection intervals are set to provide at least two inspection opportunities per number of

missed or inadequately performed, there will be at least one other opportunity to detect and correct the condition. The Board would expect that the possibility of a rapidly propagating crack, such as some of the cracks in the fatigue region on the accident airplane, would be considered in establishing an appropriately conservative inspection interval.

The Safety Board recognizes that for repairs that are supported by credible and detailed engineering documentation substantiating that the repair was performed in accordance with the applicable SRM,[7] external visual examinations may be sufficient to establish that hidden damage is not likely to exist under the repair doubler. However, for all other repairs, additional inspection techniques, such as the newly developed NDI methods or removal of the doubler, will be necessary.

Therefore, the Safety Board believes that the FAA should issue an AD requiring all operators of transport-category airplanes with pressure vessel repairs identified as a result of applying the criteria discussed in Safety Recommendation A-03-07 (other than those covered by SB 747-53A2489) to (1) immediately remove the repair doubler to determine whether hidden damage that could lead to MSD or fatigue cracking is present and, if so, repair the damage in accordance with the applicable SRM or (2) perform repetitive visual and NDI inspections for MSD and fatigue cracking at appropriately conservative intervals until the doubler is removed and, if any cracking is detected, immediately remove the doubler and repair the damage in accordance with the applicable SRM. The results of these inspections should be provided to the FAA. The only repairs that should be eligible for exemption from these requirements are those that are supported by credible and detailed engineering documentation substantiating that the repair was performed in accordance with the applicable SRM and only after a visual inspection to confirm that the repair conforms to that documentation.

The Safety Board notes that the findings of this investigation to date and the findings from other 747 inspections performed as a result of SB 747-53A2489 indicate that improper repairs are not an isolated occurrence. The Board further notes that the risk of catastrophic consequences as a result of improper pressure vessel repairs is not limited to 747s. The Board is concerned that maintenance personnel may not be sufficiently aware of the potentially catastrophic consequences of improper pressure vessel repairs. Therefore, the Board believes that the FAA should inform maintenance personnel about the circumstances of this accident and emphasize that improper repairs to the pressure

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flights or flight hours it would take for a visually detectable crack to grow large enough to cause a failure in flight."

[7] The Safety Board would expect such substantiating documentation to include, at a minimum, the following: a complete description of the nature and location of the damage; drawings/diagrams depicting the size and shape of the repair; applicable engineering guidance and maintenance instructions; work cards containing a complete description of the steps that were followed to remove and repair the damage and inspector and Designated Engineering Representative signoffs, as applicable; and evidence that materials used in the repair (including fasteners and clips) meet applicable materials specifications. The Board would not consider an unsupported assertion that the repair was performed in accordance with the applicable SRM, such as was contained in the maintenance records for the China Airlines repair, to be sufficient substantiating documentation.

vessel may be hiding damage that allows the development of MSD and fatigue fracturing that could lead to structural failure.

Finally, the Safety Board also notes that the Boeing SRM does not include in its repair instructions any mention of the possibility of structural failure resulting from improper repairs and hidden damage. Therefore, the Board believes that the FAA should require the manufacturers of pressurized transport-category airplanes to include in their SRMs, training programs, and other maintenance guidance, warnings about the possibility of structural failure resulting from hidden damage.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

> Establish appropriate criteria (taking into account the size of the repair and other relevant considerations) to identify those pressure vessel repairs to transport-category airplanes that could be hiding damage that, if not addressed, may lead to multiple-site fatigue damage and fatigue cracking and could result in structural failure of the airplane. (A-03-07)
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> Issue an airworthiness directive requiring all operators of transport-category airplanes with pressure vessel repairs identified as a result of applying the criteria discussed in Safety Recommendation A-03-07 (other than those covered by Service Bulletin 747-53A2489) to (1) immediately remove the repair doubler to determine whether hidden damage that could lead to multiple-site fatigue damage (MSD) or fatigue cracking is present and, if so, repair the damage in accordance with the applicable structural repair manual (SRM) or (2) perform repetitive visual and nondestructive inspections for MSD and fatigue cracking at appropriately conservative intervals until the doubler is removed and, if any cracking is detected, immediately remove the doubler and repair the damage in accordance with the applicable SRM. The results of these inspections should be provided to the FAA. The only repairs that should be eligible for exemption from these requirements are those that are supported by credible and detailed engineering documentation substantiating that the repair was performed in accordance with the applicable SRM and only after a visual inspection to confirm that the repair conforms to that documentation. (A-03-08)
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> Inform maintenance personnel about the circumstances of this accident and emphasize that improper repairs to the pressure vessel may be hiding damage that allows the development of multiple-site fatigue damage and fatigue fracturing that could lead to structural failure. (A-03-09)

Require the manufacturers of pressurized transport-category airplanes to include in their structural repair manuals, training programs, and other maintenance guidance, warnings about the possibility of structural failure resulting from hidden damage. (A-03-10)

Acting Chairman HAMMERSCHMIDT and Members GOGLIA and CARMODY concurred in these recommendations.

By:

Original Signed

Ellen G. Engleman
Chairman