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National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: December 15, 1993

In reply refer to: A-93-153 through -160

Honorable David R. Hinson
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On April 19, 1993, at 1552 central daylight time, a Mitsubishi MU-2B-60, registered in the United States as N86SD and operated by the State of South Dakota Department of Transportation as a public use airplane, collided with a silo on a farm near Zwingle, Iowa, while attempting an approach to an emergency landing at Dubuque Regional Airport (DBQ), Dubuque, Iowa. The airplane was destroyed in the collision and postcrash fire. The captain, first officer, and the six passengers aboard were fatally injured. Instrument meteorological conditions existed at the time. The flight originated from Cincinnati, Ohio, at 1406, on an instrument flight rules (IFR) flight plan.[1]

While the MU-2 was in cruise flight at flight level 240, a hub arm on the airplane's left propeller hub (Hartzell model HC-B4TN-5GL) failed, releasing the propeller blade and a portion of that hub arm.

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[1]For more detailed information, read Aircraft Accident Report--"In-Flight Loss of Propeller Blade and Uncontrolled Collision with Terrain, Mitsubishi MU-2B-60, N86SD, Zwingle, Iowa, April 19, 1993" (NTSB/AAR-93/08)

The National Transportation Safety Board has determined that the probable cause of this accident was the fatigue cracking and fracture of the propeller hub arm. The resultant separation of the hub arm and the propeller blade damaged the engine, nacelle, wing, and fuselage, thereby causing significant degradation to aircraft performance and control that made a successful landing problematic.

The cause of the propeller hub arm fracture was a reduction in the fatigue strength of the material because of manufacturing and time-related factors (decarburization [loss of carbon], residual stress, corrosion, mixed microstructure, and machining/scoring marks) that reduced the fatigue resistance of the material, probably combined with exposure to higher-than-normal cyclic loads during operation of the propeller at a critical vibration frequency (reactionless mode[2]), which was not appropriately considered during the airplane/propeller certification process.

Previously, on September 27, 1991, in Utica, New York, the Safety Board investigated another accident involving an MU-2B-60 airplane in which a propeller blade had separated from the right propeller hub, model HC-B4, manufactured by Hartzell. Although the engine mounts did not fail completely in this accident, the pilot could not arrest his descent after the hub failed and the engine shut down. He said that he was "just barely" able to reach the runway.

Investigation of the Utica accident, including metallurgical examination at the Safety Board's Materials Laboratory, revealed that the propeller hub arm had fractured as a result of fatigue cracking that initiated from multiple initiation sites on the surface of the pilot tube hole.[3] Corrosion pitting was found on the surface of the pilot tube hole in the hub arm. However, the fatigue initiation sites could not be attributed to specific corrosion pits.

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[2]A mode of vibration of the propeller assembly excited by changes in a tailwind component acting on the blades as they revolve during ground operations. During the reactionless mode of vibration, pairs of opposite blades vibrate in phase with one pair vibrating forward while the other pair vibrates aft. Such vibration results in reverse bending stresses in the blade and hub arms with little or no relative motion or vibration of the mounting flange because the resulting motion of the blades is balanced on the propeller shaft.

[3]The pilot tube is inserted in the bore of the hub arm and protrudes from the hub to facilitate attachment of the propeller blades.

Metallographic examinations made on the broken hub from the Zwingle accident, the broken hub from the Utica accident, another hub found to contain a crack, as well as three other hubs that were manufactured using the same heat treatment and machining processes, disclosed that all had similar mixed microstructure and varying amounts of decarburization, corrosion, and machine marks. The manufacturer changed the heat treatment process for the propeller hubs in 1981 and the machining process in 1984. These changes have minimized those factors that reduce the fatigue resistance of the material. However, hubs manufactured using the earlier processes are installed on a number of airplane models other than the MU-2.

As part of the process of propeller certification, the manufacturer is required to identify the frequency ranges of resonant vibrations, and the airplane, engine, and propeller combinations are subsequently certificated to assure that the time spent operating at propeller speeds that correspond to these resonant frequencies is minimized. As a part of this certification process, Hartzell identified the resonant frequency for the reactionless mode of vibration, and the operating range of the engine and propeller on the MU-2B was limited accordingly.

The fatigue origin areas for both the Zwingle and Utica hubs were aligned with the direction of the resultant thrust and drag loads on the propeller blades, but were on opposite sides of the hub bore. The steady stresses due to normal flight loads are greater on the side of the hub toward the direction of rotation. However, the cyclic stresses from both normal operating loads and the reactionless mode of vibration are equal in both sides of the hub. Thus, while cracking from cyclic loading could initiate on either side of the hub, the Safety Board believes that, because the origin area of the fatigue crack on the Utica hub was on the side of the bore that has lower steady stresses during normal operation, the failure of this hub was more likely caused by the stresses imposed during operation in the reactionless mode.

Tests conducted following the Zwingle accident provided further evidence to support the conclusion that the fatigue initiation on the hub from the Utica accident was a result of exposure to the reactionless mode vibration loads. The tests indicated that despite precautions taken to avoid operating the propeller in a revolutions-per-minute (RPM) range that matches the resonant frequency of the reactionless mode of vibration, the resonant frequency of the reactionless mode can increase to within the normal ground operating RPM range for the MU-2B when the propeller contains worn or repaired blades. The blades recovered from the Utica accident were found to be within the conformity limits prescribed in the airplane's maintenance and repair manual, but were worn or blended at the tips to the extent that the reactionless mode resonant frequency of the propeller assembly was significantly higher than that which had been established for nominal blades in the initial certification process. It was demonstrated that the resonant frequency corresponded to propeller speeds normal for the MU-2B ground operating range.

Two of the propeller blades that were originally installed on the hub that failed in the Zwingle accident were also recovered. Testing by Hartzell demonstrated that the resonant frequency of the reactionless mode for these blades would also be above the minimum ground idle RPM. In addition, the Safety Board believes that the characteristics of the hub arm fracture surface are consistent with a reactionless mode initiation of the fatigue crack. The fracture surface contained a primary discolored zone emanating from the origin area. In this area, the already established crack front did not continue propagating in its established shape and color. Instead, there appeared to be two separate cracks initiating from each side of the crack tip, and the initial crack propagation was relatively clean for some distance away from the discolored zone. Crack reinitiation from an already large, established crack front, such as that found in the initial discolored zone, is not typical and signifies a change to a much lower cyclic stress. The Safety Board believes that the initial crack propagation was caused by the reactionless mode vibration modes and that continued propagation was a result of normal flight cyclic loads.

The two factors that make the MU-2 airplane particularly susceptible to propeller operation of the reactionless mode resonance are the relatively small margin between the nominal propeller natural frequency and the lower limit of the ground idle propeller speed range of the airplane, and the liberal applications of the wear and repair limits for the propeller blades prescribed in the approved manuals. A review of other airplane models using the Hartzell HC-B4 hub disclosed that all of them have greater certification margins and tighter propeller blade limits.

The Safety Board believes that the minimum ground idle RPM speed of the HC-B4 propeller on the MU-2B airplane should be increased to provide a greater margin between the resonant frequency of the reactionless mode and the ground idle speed. In addition, the distance between the tips of the HC-B4 propeller blades and the closest blade station should be substantially reduced to reduce the uncontrolled area from which material can be lost and to minimize the possibility of an increase in the resonant frequency of the reactionless mode.

The Federal Aviation Administration (FAA) has indicated that a study of the propensity of other propeller/airframe combinations to experience the reactionless mode of vibration is being conducted and that appropriate action will be taken to ensure that aircraft operations are kept out of this mode of vibration as much as possible. The Safety Board supports this effort and urges the FAA to complete this study and to issue appropriate airworthiness directives.

The FAA has not yet been able to verify whether any hubs have been operated on MU-2 airplanes and subsequently installed on other model airplanes. The potential exists for damage induced from reactionless mode stresses while on an MU-2 airplane to lead to failure while on another model airplane. Therefore, the Safety Board urges the FAA to immediately determine the whereabouts of all 4-bladed Hartzell propeller hubs that have been installed at any time on MU-2 airplanes, and require immediate inspections for potential fatigue damage in the hubs.

While the Safety Board believes that the evidence indicates that both of the failed hubs (from the Utica and Zwingle accidents) were the result of operation of the propellers at the reactionless mode resonant frequency, strain surveys of the hubs while exposed to such operation have shown that the maximum stresses remain well below those that theoretically could cause a fatigue crack initiation in hub material of normal strength, absent the fatigue resistance-reducing factors identified in the probable cause. Furthermore, because the effect of factors, such as mixed microstructure, decarburization, corrosion and machine marks, on fatigue properties cannot be precisely quantified, the Safety Board cannot exclude the possibility that the fatigue cracks were initiated by the normal operating loads on the MU-2B propeller hubs. The Safety Board understands that the stresses imposed on the MU-2B-60 hub are higher than the stresses imposed on most other airplane propeller hubs. Nonetheless, because of the possibility of failures due to normal loading, the Safety Board believes that the FAA should identify Hartzell steel propeller hubs on other airplanes that have high stresses during flight and should conduct a designated safety inspection for cracks in the pilot tube hole of the hub arm on those hubs that have high amounts of operating time and that were manufactured with pilot tube holes machined prior to heat treatment. The Safety Board also believes that the reduced fatigue properties are present on the 3- and 5-bladed Hartzell hubs, and that similar actions should be considered for hubs with similar stress levels.

The investigation of this accident also led to some concerns in the area of air traffic control (ATC). Following the propeller hub failure, the airplane probably had sufficient altitude for the flightcrew to have attempted an instrument landing system (ILS) approach and landing at Clinton (CWI), but ATC did not offer this option to the flightcrew. The difficulty of the approach would most likely have been compounded by the low 400-foot ceiling. Also, the flightcrew would have had to fly some distance southwest of the airport to align the airplane for an ILS approach to runway 03. The reason that CWI was not offered to the flightcrew was that the center radar controller did not have readily available weather information for CWI to issue to the flight. Weather information for CWI was generated by the automated weather observing system, which is not available on the computer terminals used by the controllers.

Moreover, the Safety Board believes that the MU-2 would have broken out of the overcast weather conditions at a higher altitude if it had been on a course toward Moline (MLI), rather than DBQ, but the flightcrew was not offered this course option by the controllers. If an airport with better weather conditions had been provided to the flightcrew, they might have used that option and had more time to select a flat, open area on the ground to crash land the airplane. In this case, the probability of flightcrew and occupant survival would have greatly increased.

The Safety Board believes that the controllers involved in this emergency should have determined that the weather at MLI was much better than that at DBQ. Moreover, they should have been aware that CWI was much closer than either MLI or DBQ and then relayed that information to the flightcrew of the MU-2. The ATC transcript revealed that an apparent lull in controller activity occurred shortly after DBQ weather conditions were provided to the flightcrew. The controllers could have spent this time more efficiently by identifying other possible diversion airports, obtaining weather sequences for one or more of these airports, and then transmitting some options to the flightcrew.

Air Route Traffic Control Center (ARTCC) radar controllers do not have an efficient means of searching through multiple weather sequences to locate an airport with the best weather conditions for landing or an adequate means of constantly displaying several terminal weather sequences. The several methods for obtaining current weather sequences are cumbersome and impractical during airborne emergency situations.

The Safety Board believes that hourly sequence reports for key airports should be constantly displayed on each sector in some manner.[4] Having only the capability of "calling up" and preserving a single weather sequence is inadequate, as the circumstances of this accident indicate. Had the appropriate weather sequences been constantly displayed, the controllers would have been immediately aware that the weather in the MLI area was considerably better. This knowledge would have provided the flightcrew with a better opportunity to land without catastrophic consequences. Therefore, the Safety Board believes that the FAA should provide all ARTCC sector positions with the capability of displaying several hourly sequence reports at once. This display should be updated automatically and displayed at all times.

Controllers do receive some level of emergency procedure training in initial and annual refresher training. However, the circumstances of this accident indicate that this training is inadequate. The Safety Board believes that the Air Traffic Control handbook, which is the basis for controller training, does not adequately address the issue of airborne emergencies. Of further relevance to this accident, the issue of finding the best possible weather for an IFR aircraft during an airborne emergency is not clearly addressed.

The Safety Board does not believe that providing training for every possible emergency scenario would be practical. However, it does believe that the problem as basic as an emergency descent for landing through IFR conditions is a common one during many airborne emergencies and that more consideration should be given in controller training for such contingencies. Controller-to-pilot and pilot-to-controller communication in various emergency situations involving ATC should be emphasized in this training. Therefore, the Safety Board believes that the FAA should enhance the Emergency Assistance section of Air Traffic Control handbook 7110.65 to fully address the issue of finding the best possible landing weather for an IFR aircraft in an emergency status and to emphasize this concept in emergency training scenarios.

As a result of its investigation of this accident, the National Transportation Safety Board recommends that the Federal Aviation Administration:

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[4]Such a practice was standard in ARTCCs prior to, and for a short time after, the advent of automated radar displays. An assistant controller manually copied the weather onto large "grease pencil" display boards in the radar room, a procedure that was somewhat labor intensive.

Determine whether any 4-bladed Hartzell propeller hubs have ever been installed on MU-2B airplanes and are now installed on other model airplanes, and issue the necessary airworthiness directives to inspect the hubs for fatigue damage. (Class I, Urgent Action) (A-93-153)

Identify airplanes that can, through a combination of the resonant RPM, the ground idle RPM range, and repair limits at the blade tip, produce the reactionless mode in the normal operating range. For those airplanes containing Hartzell hubs at risk for reduced fatigue properties (manufactured prior to April 1984), require inspection for cracks in the pilot tube hole. (Class II, Priority Action) (A-93-154)

Perform a designated safety inspection for cracking in the pilot tube hole on high time Hartzell 3-, 4-, and 5-bladed propeller hubs that are found to have high operating stress and that were manufactured with the pilot tube holes finished machined prior to heat treatment. (Class II, Priority Action) (A-93-155)

Increase the minimum ground idle RPM speed of the HC-B4 propeller on the MU-2B airplane to provide a greater margin between the resonant frequency of the reactionless mode and the ground idle speed. (Class II, Priority Action) (A-93-156)

Revise maintenance and repair limits for propeller blades on HC-B4 hubs on MU-2B aircraft to reduce the length of the uncontrolled area at the blade tip to minimize the in-service increase in the reactionless mode frequency. (Class II, Priority Action) (A-93-157)

Enhance the Emergency Assistance section of Air Traffic Control handbook 7110.65 to fully address the issue of selecting the best possible diversion airport for an IFR aircraft in an emergency status. (Class II, Priority Action) (A-93-158)

Provide all ARTCC sector positions of operation with the capability of displaying several hourly weather sequence reports at once. This display should be updated automatically, and displayed at all times. (Class II, Priority Action) (A-93-159)

Provide expanded emergency procedures training for air traffic controllers. The general capabilities of airplanes in various emergency scenarios involving air traffic control should be a focal point of this training, and past air traffic control-related accident reports should be used. (Class II, Priority Action) (A-93-160)

Chairman VOGT, Vice Chairman COUGHLIN, and Members LAUBER, HAMMERSCHMIDT, and HALL concurred in these recommendations.

By: Carl W. Vogt
Chairman