**INCIDENT**

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| **Aircraft Type and Registration:** | BN2-A Mk III-2 Trislander, G-BEVT |
| **No & Type of Engines:** | 3 Lycoming 0-500-E4C5 piston engines |
| **Year of Manufacture:** | 1977 |
| **Date & Time (UTC):** | 24 April 2005 at 1335 hrs |
| **Location:** | Alderney, Channel Islands |
| **Type of Flight:** | Public Transport (Passenger) |
| **Persons on Board:** | Crew - 1 Passengers - 9 |
| **Injuries:** | Crew - None Passengers - None |
| **Nature of Damage:** | Propeller de-icer boot separated from propeller |
| **Commander's Licence:** | Airline Transport Pilot's Licence |
| **Commander's Age:** | Not relevant |
| **Commander's Flying Experience:** | Not relevant |
| **Information Source:** | Information submitted by the operator and AAIB enquiries as part of an earlier investigation involving this aircraft |

**Synopsis**

Following an accident where a propeller de-icer boot separated and penetrated a window, injuring a passenger, the AAIB investigated a subsequent de-icer boot separation on the same aircraft. The investigation found that the quality of the adhesive bond between the boot and the blade is dependent upon meticulous adherence to correct procedures and practices. No safety recommendations are made because, industry wide, satisfactory attachment of the boots is routinely achieved using published procedures and correct materials. However, apparently quite minor deviations in the process can cause a reduction in bond strength which can lead to boot separation.

**Background**

On 23 July 2004 Trislander G-BEVT was involved in an accident caused by the separation of a propeller de-icer boot from the left propeller. That accident was the subject of AAIB report number 1/2006 published on 11 January 2006. Brief details of this occurrence were as follows:

Shortly after takeoff from Guernsey Airport, a loud crack or bang was heard in the aircraft's cabin. The aircraft commander was told by a colleague in the cabin that one or more passengers had been injured and that a cabin window was broken. The aircraft returned to Guernsey Airport and landed having been airborne for approximately four minutes. After the passengers had disembarked, the pilot noticed that a de-icer boot had separated from the left propeller and was lying on a seat inside the cabin, adjacent to the broken window.

The investigation found that the accident was caused by the separation of a de-icer boot from the left propeller during takeoff. Laboratory work indicated that the de-icer boot had separated due to peel stresses generated by forces on the propeller. The peel stresses arose because of physical or contamination damage to the adhesive (often called 'cement') bond at the root of the blade.

The propeller manufacturer's blade manual required the de-icer boots to be bonded to the blade and then for a filler material to be applied at the root end of the boot. Finally the edges were to be coated with a sealer. The function of the filler material was to prevent environmental damage to the bond. The filler material had not been applied and as a result, environmental damage, or possibly physical damage, to the adhesive at the root of the boot had occurred. This left a small disbonded area which grew under stress until the de-icer boot finally separated.

As a result of this event the UK CAA identified approximately 100 propellers which had been overhauled without using the required filler. The propellers had all been overhauled by the same organisation within a six year period, which is the calendar overhaul period for these propellers. The UK CAA had also been working with the propeller manufacturer to establish an inspection and rectification regime for the affected propellers. This involved inspections and, if the condition of the adhesive bond was satisfactory, the retrospective application of filler.

The second incident, the subject of this report, occurred to the propeller on the right wing of the same aircraft. Normally, the AAIB would have regarded it as a non-reportable occurrence. However, the propeller involved had been overhauled by the same organisation, using correct procedures and materials, including the use of the correct filler material. Initial examination indicated that the cause of de-icer boot separation was not the same as before. Consequently, this second incident became the subject of this separate report.

**History of the flight**

The aircraft departed Alderney terminal for Guernsey with nine passengers on board. At about 60 kt during the take-off ground roll the pilot heard a muffled bang. All indications were normal so the takeoff was continued but on arrival at Guernsey, a de-icer boot was missing from the right propeller. There were no injuries sustained and no obvious damage to the aircraft. The de-icer boot was found on the runway at Alderney.

**Technical investigation**

The propeller, part number HCC3YR2UF serial CK3663A, was quarantined for investigation. It had accumulated 175 hours usage since it was overhauled on 2 November 2004 when new de-icer boots had been fitted. The overhaul work pack showed that the de-icer boots had been fitted in accordance with Hartzell Blade Manual 133C, including the use of Hartzell approved 3M EC 1300L adhesive and the appropriate filler. The boots fitted were not the specified BF Goodrich parts but were an acceptable alternative which carried the part number MHG2778/B. The propeller and boot were returned to the AAIB for investigation, together with a number of similar boots from the same manufacturer, which the operator had removed from seven other propellers.

An initial examination of the detached boot showed that failure had occurred between the adhesive and the boot and that there was virtually no adhesive left on the boot. There was no evidence of any gross contamination of the boot or propeller surfaces that could have hindered adhesion.

The only areas of the boot that retained significant amounts of adhesive were along the centre of the boot where it is bent around the leading edge of the propeller blade. These areas were examined and found to have smooth adhesive surfaces, indicating that no bonding to the blade had occurred. Examination of the propeller blade showed that the adhesive remained well bonded to this substrate and confirmed that bonding to the boot had not occurred in a number of locations along the leading edge. These areas corresponded to areas on the boot where the adhesive had been retained.

All the boots examined showed areas, of varying sizes along the blade leading edge, that had not been bonded. It is known that the leading edge is an area where it can be difficult to achieve adhesion because of, the complex curvatures present, and the stiffness of the boot due to the embedded heating wires. These poorly bonded areas provide a means for moisture to 'fast-track' to the centre of the joint and, as a result, possibly accelerate the rate of degradation of the adhesive bond.

The appearance of the boot that separated was in contrast to the boot from the previous failure, which retained noticeably more adhesive, with significantly more interfacial failure between the adhesive and the propeller. Furthermore, the boot did not show any evidence of moisture ingress at the root end, which had been identified as the probable cause of failure in the previous case. There was also evidence of apparently brittle adhesive cracking on this boot, which was not seen on either of the other boots removed from this propeller or on any of the other boots submitted for assessment.

Examination of the boots taken from the other propellers showed failure mechanisms similar to the previous failure, often with more interfacial failure between the adhesive and the propeller. This might be expected since it was believed that these boots were all bonded with the same adhesive, ie Bostik 2402. Furthermore, evidence of moisture ingress at both the root and the tip was found on a number of the boots, which supported the conclusion that the previous failure resulted from moisture ingress and that failure initiated at the root.

A comparison between all the boots bonded with Bostik 2402 and the failed boot, which was bonded with 3M 1300L, shows that with Bostik 2402, with one exception, there was a significantly greater degree of interfacial failure between the adhesive and the propeller. Furthermore, all the boots bonded with Bostik 2402 retained noticeably more adhesive. Therefore, it can be concluded that, for boots bonded with Bostik 2402, the weakest joint is between the adhesive and the propeller, particularly once moisture has penetrated into the joint. In contrast, for the three boots from the right propeller of G-BEVT, which had all been bonded with 3M 1300L, the weakest joint was that between the adhesive and the boot.

According to the laboratory report, both adhesives are based on polychloroprene rubber but Bostik 2402 is crosslinked using a curing agent (Bostikure D). This improves the resistance of the adhesive to heat and fluids. The origin of the rubber material used in the de-icing boots is not known, and it is possible that changes in the formulations of either the adhesives or the boots may have occurred since qualification. The composition of Bostik 2402 will change during 2006 in order to eliminate the solvent Toluene. Since the solvent will affect drying and application times, this could require a modified application technique. Furthermore, processing aids used during boot manufacture, to ease ejection from the mould, will reduce the bond strength unless they are removed using an appropriate surface cleaning technique.

There are also application differences between the two adhesives, and on occasion, differences between the relevant sets of instructions for the same adhesive. The 3M data sheet for 1300L states that the adhesive should be applied to both surfaces, allowed to dry for a maximum of 4 minutes and be bonded within 8 minutes. In contrast, the advice for Bostik 2402 is that the adhesive should be allowed to dry for between 5 and 15 minutes before bonding. The overhauler might follow the instructions contained in the propeller manufacturer's blade manual, or the boot manufacturer's instructions, or the directions in the adhesive manufacturer's product data sheet. However, Bostik 2402 adhesive is not mentioned in the Hartzell blade manual 133C but it is permitted in the BF Goodrich Installation Manual. That manual states drying and application times of one hour for the first coat and 10 to 30 minutes for the second. This varies from the Product Data sheet, which gives times of 20 to 30 minutes for the first coat and 5 to 15 minutes for the second coat.

**Further AAIB enquiries**

During visits to several propeller overhaul and repair organisations, the AAIB investigator was advised of a number of issues which might affect the adhesive bond strength and quality. These included temperature, humidity, cure time of the paint finish on the blade, the exact handling technique which an installer may use to apply the boot, the technique employed to brush the adhesive on to the boot, drying time between the first and second coats of the adhesive and compatibility issues between the boots and adhesives. The laboratory finding that Bostik 2402 might be stronger than 3M 1300L was supported generally by anecdotal evidence, and in particular by tests carried out by the manufacturer of the particular boot involved in this incident. There was some common experience of adhesion problems with this type of boot, although all makes of boot had been the subject of difficulties from time to time. One respected organisation, with no recent history of boot failures, described a period when the same individual on the same day would achieve results ranging from satisfactory to unserviceable. The organisation also described a complex and ultimately inconclusive investigation into the causes. One common experience was that often, particularly with the subject type of boots, little adhesive was left on the boot itself even though the first coat is applied directly to it. This led to discussion about the internal surface finish of the boot. It was observed that the boots had a textured surface which might require the adhesive to be stippled in rather than being simply brushed on with long, straight, brushstrokes. However, little of this perceived difficulty could be validated.

During this investigation the AAIB identified the following good practices which increased the likelihood of a satisfactory bond.

1 Environmental conditions

While bonding can be carried out in the field, it is ideally conducted in a dedicated, clean environment, free of condensing humidity and within the recommended temperature range. For example, Goodrich recommend 65-75ºF and a Relative Humidity (RH) below 75%; outside this range best results may not be achieved. Higher RH requires additional drying time and installation in conditions below 50ºF or above 90% RH is not recommended. Because the thermal mass of the propeller blades is significant, it is best practice to allow the blades to acclimatise to the temperature of the controlled environment for a suitable period before undertaking the bonding process.

2 Selection of materials

There is often a choice of boots and adhesive systems available. Although alternatives have been approved locally, the manufacturer's documentation is more specific and will specify certain options for adhesives, fillers and cements. Although the industry itself has views on which are the most consistent performers, consistently good results are being achieved through adherence to the manufacturer's instructions.

3 Preparation

Apart from general standards of cleanliness, degreasing and handling, there are also issues concerning the use of correct paints and primers (or in some cases the prohibition of paints) which vary from system to system. Correctly prepared substrates are essential to reliable bonding.

4 Use of materials

The adhesives must have been correctly stored and be within their shelf life. They must be free of contamination, and correctly mixed. When mixing large volumes, the process of opening cans and mixing correct amounts can introduce contamination, ageing and incorrect mixing. The use of small cans, mixing the complete contents and disposing of the unused adhesive, guarantees correct quantities for mixing; ultimately it may also avoid waste and be more economic. Mixing must be thorough and in accordance with the adhesive manufacturer's instructions. This may take more time than expected.

5 Application techniques

Long, even, brush strokes are generally used, but it may be that this causes the adhesive to 'bridge' the peaks of a textured surface rather than adhere uniformly. The boots are pressed into place with a roller but it is necessary to position them on the blade by hand. This can be a difficult task for one person and because a contact adhesive is used, it may become difficult to eliminate air bubbles and gaps.

6 Curing times

Different adhesives have different curing times and different times must be complied with between the first and second coats. Also, the blades themselves may have been overhauled and repainted, in which case incompletely cured paints or solvents could affect the adhesive bond.

**Conclusion**

In the light of these findings, it appears that propeller de-icing boots can routinely be satisfactorily bonded if published procedures and good practice are meticulously followed. However, apparently quite minor deviations in the process can cause a reduction in bond strength, or allow the generally poor peel strength of adhesives to be exploited by mechanical or environmental damage. This can lead to boot separation.