BEA
Bureau d'Enquêtes et d'Analyses
pour la sécurité de l'aviation civile

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INVESTIGATION REPORT

Accident to Fokker 27-500 registered I-MLVT on 25 October 2013 during initial climb from Paris-Charles de Gaulle Airport

[(1)]Except where otherwise stated, times in this report are local.

Time	Around 1:25[(1)]
Operator	Miniliner
Type of flight	Public transport, cargo
Persons on board	Captain (PF) and copilot (PM)
Consequences and damage	Aircraft severely damaged

Loss of a propeller blade then part of the left engine during initial climb, in-flight turn back, emergency landing

1 - HISTORY OF THE FLIGHT

[(2)]Since renamed Dole-Jura airport.

The crew took off at 01:22 from runway 09R at Paris-Charles de Gaulle Airport for a postal cargo flight to Dole Tavaux airport (Jura)[(2)]. At a height of approximately 1,300 ft, they heard the noise of an explosion coming from the cargo area. At the same time, they noticed the illumination of the left "*engine fire*" indicator light, along with the associated aural warning. The crew declared an emergency and implemented the engine fire procedure, but found that the feathering control was stuck. The captain looked out of the window and saw that the fire had gone out and that part of the left engine was missing. The aeroplane could still be flown and the crew turned back and landed without further incident at Paris-Charles de Gaulle. The forward part of the left engine and the propeller, broken up in several parts, were found in a field directly underneath the path of the initial climb from runway 09R.

2 - ADDITIONAL INFORMATION

2.1 Examination of the aircraft

I-MLVT was fitted with two Rolls-Royce Dart 532-7 engines.

The forward part of the engine, from the first compressor stage forward, and the propeller were absent. Traces of fire were visible on the rear of the engine nacelle.

The BEA investigations are conducted with the sole objective of improving aviation safety and are not intended to apportion blame or liabilities.

On the left side, the fuselage had a vertical hole that opened from the outside to the inside, and numerous small impacts. On the right side, it was punctured vertically, from the inside to the outside of the fuselage, with a hole of a similar size to the hole on the left fuselage. Inside the fuselage, the postal freight container, between the two puncture holes in the fuselage, was cut from side to side. The electrical cable bundles running along the fuselage side walls had been cut.

View of left side of aircraft

View of right side of aircraft

The forward part of the engine was found in a field directly underneath the path of the initial climb from runway 09R. Two of the four propeller blades (Nos. 3 and 4) were still attached to the engine, one blade (No. 1) had separated from the engine but was retained by the propeller de-icing system supply cable. The fourth blade (No. 2) was found about 600 m from the engine and the rest of the propeller.

2.2 Flight recorders

I-MLVT had two magnetic tape flight recorders.

The Flight Data Recorder (Sundstrand 4100) records 12 variables over a 25-hour recording period. The event flight was on the recording, but only four variables (altitude, indicated airspeed, heading and vertical acceleration) were valid. No engine-related variables were recorded. The recording stopped during the initial climb at a height of approximately 1,300 ft.

The Cockpit Voice Recorder (Sundstrand AV 557 C) contained 30 minutes of audio recording, including the event flight. The recording stopped during the initial climb. Spectral analysis showed that, from take-off to the end of the recording, the engine and propeller speeds were nominal.

When blade No. 2 passed through the fuselage, it cut through the electrical cables supplying power to the recorders.

2.3 Dowty Propellers R193/4-30-4/61 propeller

I-MLVT had Dowty Propellers R193/4-30-4/61 propellers.

The R193/4-30-4/61 is a propeller with four variable-pitch metal blades, developed in the 1950s by Dowty Rotol Ltd.

In 1990, Dowty Rotol Ltd became Dowty Aerospace Gloucester, and later Dowty Propellers, a GE Aviation brand.

The propeller comprises four main assemblies:

- the hub, central part of the propeller;
- the hub attachment group, which secures the propeller to the engine shaft;
- the oil tubes, which lubricate and ensure the operation of the pitch change mechanism;
- the blade group (Figure 1) and its de-icing overshoe.

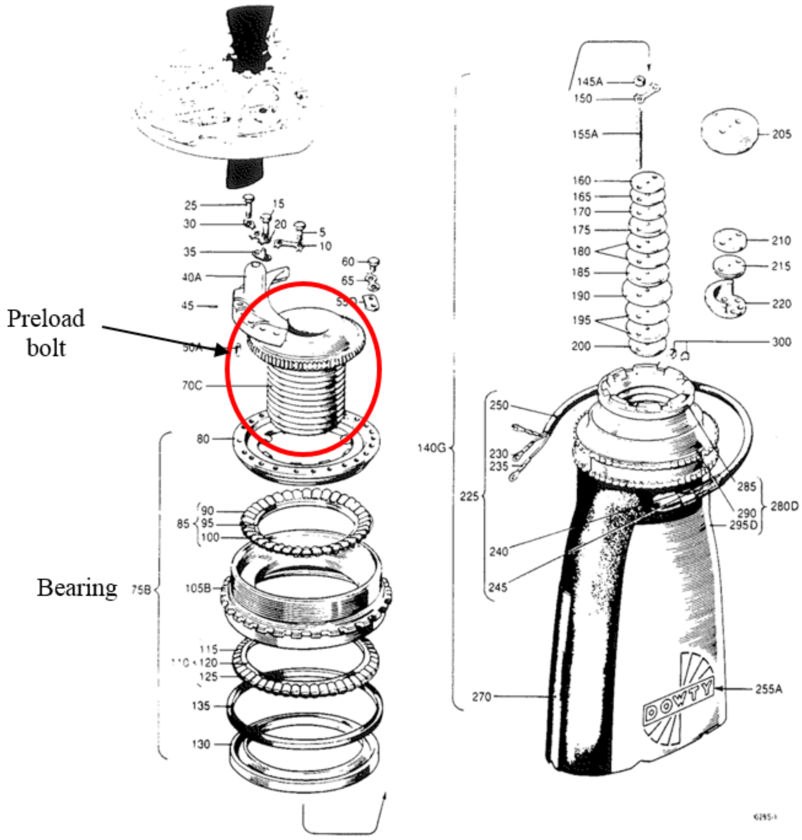

Figure 1: Exploded view of a propeller blade root, taken from the propeller OHM[3]

[3] OHM: Overhaul Manual.

Each blade comprises a profile and a root, which in turn is made up of a bearing and a pre-load bolt. The bearing allows the blade to rotate in the hub, which is how the pitch is changed. The bolt is used to assemble and pre-load the bearing. The bolt tightening operation is described in the OHM. It requires the use of a hydraulic bench on assembling and disassembling the blade.

The blades are attached to the hub by bolting the central race of the blade root bearing, which has an external (male) thread, into the hub arm, with an internal (female) thread and removed by unscrewing it from the same. These operations also require the use of a hydraulic bench, because of the tightening torque values specified by the manufacturer.

When the blade is assembled, before attachment to the hub, the OHM requires the bearing to be pre-loaded to an extension value within a certain specified range. Bearing extension is obtained by tightening the blade pre-load bolt. If the bearing extension is within the recommended range, this means that the bolt and bearing have been pre-loaded to an optimum degree, and this limits the in-service loads on the bolt.

The left propeller of I-MLVT was manufactured in 1955 and, according to the manufacturer, the bolt in question was manufactured in the 1960s (information deduced from the P/N).

2.4 Examination of blade No. 2 and its pre-load bolt

Examinations of the aircraft and blade No. 2 established that the blade separated from the left propeller and struck blade No. 1, causing it to separate from the propeller. Blade No. 2 separated from the propeller as a result of fatigue failure in its pre-load bolt, in the fillet, approximately 8.7 mm below the bolt head.

Detailed examinations with a scanning electron microscope (SEM) showed the presence of fatigue striations, confirming the presence of a crack propagation area under cyclic loading (40% of the total bolt cross-section). The high-relief area (60% of the remaining cross-sectional area) had numerous dimples, which were characteristic of a sudden ductile fracture.

Figure 2: fracture pattern on blade No.2 pre-load bolt

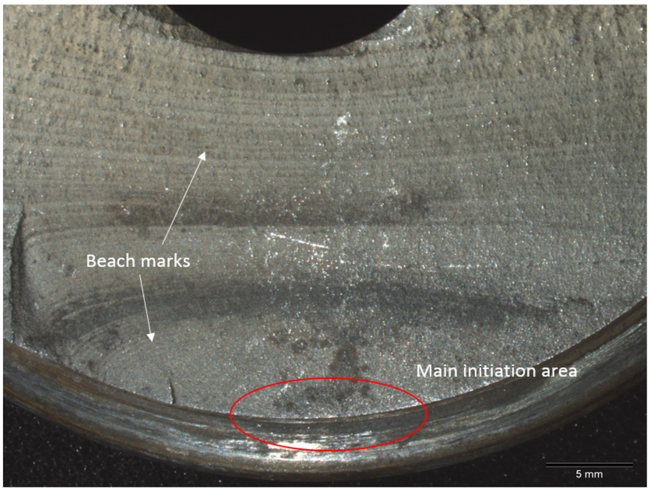

Figure 3: close-up of the fracture pattern, initiation crack area

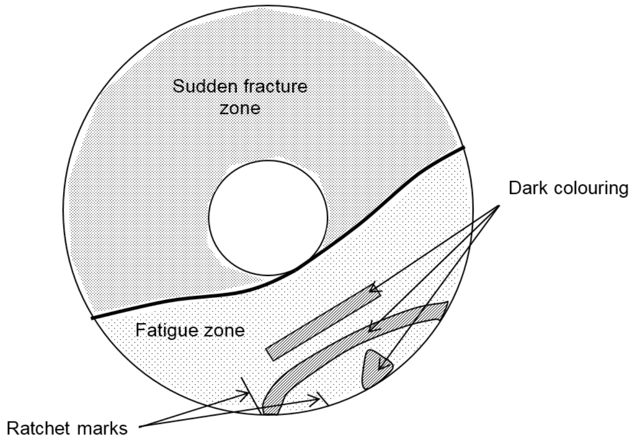

Figure 4: Fractographic description of the fracture surface
of blade No. 2 pre-load bolt

By observing the beach marks (concentric lines at the start of propagation, visible on Figure 3), the crack initiation area could be determined; it was located on the leading edge side of the blade. The presence of two ratchet lines suggested that two secondary cracks were also initiated and propagated.

The main crack initiation area locally presented a pattern with porosities (*Figure 6*). An inclusion was also observed, 100 µm from the fracture pattern. Through chemical analysis, it was determined that it was a non-metallic manganese sulphide (MnS) inclusion.

In addition, numerous open cavities, and even cracks were observed on the side of the bolt.

No prior damage (tool impact, machining fault, etc.), no corrosion pitting and no geometric defects were observed at the main crack initiation area.

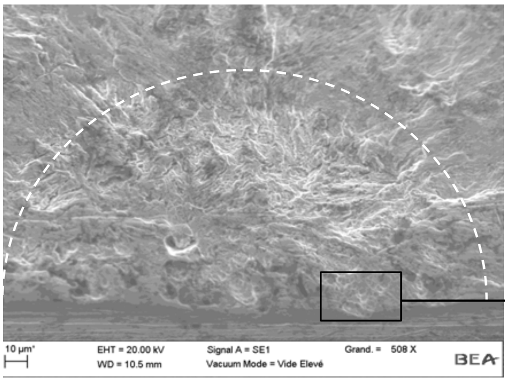

Figure 5: morphology of the main crack Initiation area

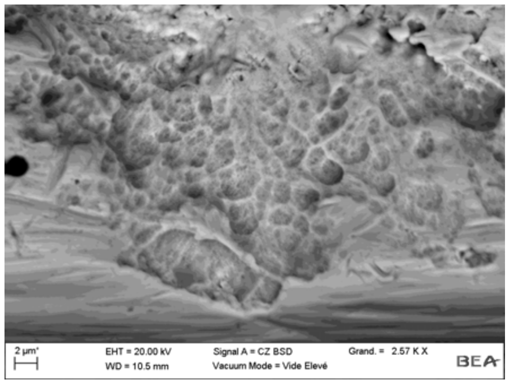

Figure 6: porosities in the main crack initiation area (detail of Figure 5)

Detailed examinations were performed in order to precisely characterise the various crack initiation areas and the bolt material (in particular the chemical nature of the material, core microstructure, hardness, morphology and composition of the surface coating, form and distribution of inclusions). For the purposes of comparison, detailed examinations were also performed on the pre-load bolts of the left propeller blades Nos. 1, 3 and 4 which had not failed.

The bolts were made of S99 steel, as per British Aerospace standard BS S99.

Examinations of the blade No. 2 bolt found that its hardness was in compliance with the standard specifications, with sulphur content slightly higher than the specifications (0.023 wt% +/- 0.003 wt%, where the specified maximum value is 0.020 wt%)[4].

[4]wt%: weight percentage.

The sulphur content of the blade Nos. 1, 3 and 4 bolts was in compliance with the specifications for S99 steel. No crack was detected in these bolts, either with magnetic particle inspection[5] or with optical inspection methods.

[5]Magnetic-particle inspection (MPI) is a non-destructive testing process that is used to detect defects that open onto the surface or are very close to the surface.

The manufacturer stated that although sulphur improves steel machinability, it is an element that is not really desirable. For commercial reasons, sulphur concentration tends to be reduced as much as possible. S99 cannot be considered as low-sulphur steel and the probability of crack initiation starting from an inclusion seems to be higher than for low-sulphur steel. Over the years, technological improvements have made it possible to produce low-sulphur steels. This was not the case in the 1960s, when the bolt in question was manufactured.

2.5 Pre-load bolt design

The rigidity of the pre-load bolt and the bearing determine the external loads that the bolt can withstand and the pre-loading on the bearing required to prevent it coming apart from the blade.

The pre-loading must be sufficient to prevent separation at the bearing seats, as a result of the external loads applied.

When a bolted assembly is tightened, tensile stresses develop in the bolt and compressive stresses develop in the assembled parts - in this case the blade root and the bearing.

The assembly is then subjected to tensile loads related to the centrifugal force. These "*compensate*" for the compressive stresses induced by the pre-loading. The role of the pre-loading is thus to provide the external loads with an "*alternative*" pathway to the pre-load bolt, by including the bearing in the load path.

The original pre-load bolt design, dated 10 December 1956, is based on an analytic calculation.

The manufacturer performed a calculation using a finite element method as part of the investigation. This showed that:

- the pre-load bolt failed in the cross-section subject to maximum stress;
- reducing the pre-loading by more than half would be sufficient to cause separation of the blade under centrifugal loads at 105% of maximum rotational speed;
- no link was identified between the main crack initiation site, the secondary crack initiation sites and the direction of the blade bending loads.

2.6 Examination of the bearings

2.6.1 Examination of the bearing pre-loading

The pre-loading value was measured for blades 1, 3 and 4 when the left propeller was disassembled and the pre-loading of all four blades on the right propeller when it was disassembled. The bearing pre-loading for blade No. 2, whose bolt failed, is not known.

The bearing pre-loading on the three blades from the left propeller was found to be below the assembly specifications(6). For the right propeller, the bearing pre-loading was within specifications, even slightly higher.

(6)There is no specified value for disassembly.

As part of the investigation, the same type of measurements were also taken on two other propellers of the same type during scheduled maintenance, in coordination with their owner. The first one (2,785 hours since previous overhaul in a US maintenance workshop) had pre-loading values that complied with the specifications. For the second one (1,002 hours since previous overhaul in the same maintenance workshop as the left propeller from I-MLVT), two blades had pre-loading values below the specifications and the other two blades had values very close to the specifications.

One operator at the US maintenance workshop stated that, in his experience, 50% of bearings came into maintenance with a pre-loading value below the minimum assembly values recommended in the OHM. In his view, loss of pre-load may be related to bearing wear, corrosion, or a change in lubricant distribution or lubricant aging inside the bearing. The measured values on both propellers during scheduled maintenance are consistent with the values that he reported from his own experience.

It was not possible to determine whether the bearing pre-loading values for the left propeller of I-MLVT were below specifications when the propeller was assembled. Nor was it possible to determine whether, over the life of the propeller, the bolt pre-loading had changed.

2.6.2 Examination of the blade root bearings

The bearings from all four left propeller blades were examined. The wear on them was consistent with their usage and the number of flying hours after overhaul. In addition to the normal wear, damage related to the event was observed.

The bearings were lubricated with grease that complied with the manufacturer's recommendations. An anti-fretting compound (FRIN) was detected in the samples from the bearings on blades Nos. 1, 3 and 4, in accordance with the specifications. It was not possible to determine whether any FRIN was present in the bearing of blade No. 2, given the large amount of earth found in the bearing following the accident.

2.7 Maintenance of I-MLVT left propeller

Dowty defined two maintenance schedules for its propellers, when fitted to Dart engines, depending on whether the aeroplane is used for commercial transport or business aviation. These schedules are detailed in two service bulletins:

- Dowty Service Bulletin SB 61-985 applies to commercial transport operators. It specifies that the propeller must be overhauled once every 4 years. This interval can be extended to 6 years, if the bearings are inspected after 3 years.
- Dowty Service Bulletin SB 61-825 applies to business aviation operators. It specifies that the propeller must be overhauled once every 5 years. This interval can be extended to 8 years, if the bearings are inspected between 3 and 5 years after the previous overhaul.

Whatever the time limit applied, the propeller must not exceed 4,500 hours between two overhauls.

The Italian Civil Aviation Authority (ENAC)[7] had authorised Mininliner, the operator of I-MLVT, to follow the propeller maintenance schedule specified in Dowty Service Bulletin SB 61-825. This decision was made because the aircraft's activity (approximately 40 flying hours per month) was closer to that of a business aeroplane than a commercial transport aeroplane.

The last overhaul of the left propeller on I-MLVT had been performed in June 2009. The propeller had flown 2,063 hours since this overhaul. A bearing inspection was planned before June 2014, in accordance with the approved maintenance schedule. Propeller maintenance therefore complied with the ENAC-approved schedule.

The maintenance workshop that performed the last overhaul decided to discontinue maintenance of R193 type propellers in July 2012. According to the European Aviation Safety Agency (EASA) regulations in force at that time[8], maintenance documentation had to be retained by the maintenance workshop for 3 years after release to service. This EASA regulation is more stringent than what is required by ICAO. The latter[9] requires that detailed maintenance records should be kept for a minimum period of one year after the signing of the maintenance release.

Note: for comparison purposes, American regulations [10] require that a certificated repair station must retain the records required by this section for at least 2 years from the date the article was approved for return to service.

[7] Ente Nazionale per l'Aviazione Civile.

[8] Part 145, chapter 145.A.55: The organisation shall retain a copy of all detailed maintenance records and any associated maintenance data for three years from the date the aircraft or component to which the work relates was released from the organisation.

[9] Annex 6, part 1, chapter 8, paragraph 8.4.2.

[10] FAR145.219 (c).

The last overhaul of the left propeller on I-MLVT had been performed more than 3 years before the accident and the maintenance workshop had destroyed all the documents relating to this maintenance operation. No copies of these maintenance documents were sent beforehand to the operator or to the owner of the aircraft. It is not mandatory to forward these documents, but the maintenance body can, of its own accord, decide to send them, to enable the operator to keep track of the maintenance operations.

It was not possible to obtain any work card or detailed maintenance records pertaining to the left propeller overhaul (with the exception of the certificates of release to service provided to the operator, and the aeroplane and propeller logbooks). In particular, the bearing pre-loading values, which are measured and recorded at the time of overhaul, could not be recovered. The maintenance workshop nonetheless stated that all the blade pre-load bolts were inspected by magnetic-particle inspection and that no crack had been detected.

Nothing in the maintenance documents provided any evidence that could explain the loss of left propeller blade No. 2.

2.8 Dating the origin of the fatigue phenomenon

By examination, it was possible to estimate that approximately one hundred beach marks were present on the bolt fracture surface. This means that at least 100 blade loading cycles would have taken place after crack initiation, for it to propagate and cause the part failure.

However, this number gives no indication of the time required for the crack to be initiated. For metals, the fatigue phenomenon takes place in three phases:

- the part service life up to crack initiation, which accounts for between 50% and more than 90% of the part's total life cycle (for low-cycle fatigue[11] and high-cycle fatigue[12]) respectively;
- crack initiation and propagation (fracture mechanics);
- final failure.

(11)Number of failure cycles not exceeding 100,000 (10^5).

(12)Failure occurs after more than 100,000 cycles.

The only phase that can be detected in maintenance is crack propagation.

It could therefore be the case that if it took around a hundred cycles for the crack to propagate, another approximately one hundred cycles may have been required for crack incubation, prior to initiation.

If it is considered that one cycle is one flight[13] of approximately one flying hour for this aircraft, it could be assumed that the cause of the fatigue phenomenon may have occurred a few hundred flying hours prior to the accident, i.e. well after the last overhaul.

(13)i.e. a take-off and landing

2.9 Other events

2.9.1 Falconair Viscount 784, registered SE-CNL

On 23 July 1967, a Falconair Vickers Viscount 784 registered SE-CNL lost its right propeller, after blade No. 1 had come apart from the propeller.

The propeller was type R130/4/20/4/12E and the blade root technology was comparable to that of the R193/4-60-4/61 propeller.

According to the Dowty Rotol Ltd investigation report, the loss of blade No. 1 could be attributed to the incorrect assembly of the blade root bearing seal. The seal was found twisted, which allowed humidity to enter the bearing and the lubricant to escape. This caused severe corrosion pitting to appear on the bearing raceways, leading to a significant loss of bearing and bolt pre-loading. The in-service loads on the blade pre-load bolt significantly increased, which caused fatigue failure in the bolt in the fillet, underneath the bolt head.

2.9.2 Manufacturer's feedback

Dowty Propellers stated that it was not aware of any similar event on this type of propeller, apart from the event described above.

The blade pre-load bolt has no service life limit. It is inspected for cracks or damage at every overhaul and is only released to service if it passes the inspection ("*on condition*" maintenance).

Dowty performed a significant proportion of maintenance operations on these propellers from the end of the 1950s until the early 1990s, the main period during which they were used. Dowty estimated that, in total, approximately 6,200 propellers have been in operation, with more than 100 million flying hours logged by this type of propeller.

Dowty indicated that replacing a blade pre-load bolt in maintenance was a rare occurrence.

2.10 Dowty and EASA actions

Following the I-MLVT accident, Dowty published a Service Bulletin (SB 61-A1152) on 20 November 2013, requiring a one-off inspection of the condition and pre-loading of blade root bearings on all types of Dowty propellers that use this technology. On 21 November 2013, EASA issued an Airworthiness Directive requiring compliance with this Service Bulletin. No similar problems on propellers in operation were identified during the inspections.

3 - LESSONS LEARNED AND CONCLUSION

3.1 Fatigue failure of blade root

The pre-load bolt on left engine blade No. 2 suffered fatigue failure, causing the blade to come apart from the propeller hub. It then interacted with blade No. 1 causing the latter to separate from the propeller hub. The imbalance created by the loss of these two blades led to the front of the engine being ripped off.

The investigation was unable to determine with certainty the cause of fatigue cracking.

The following elements may have contributed to the pre-load bolt fatigue failure:

- ❐ insufficient bolt pre-loading, leading to an increase in the loads applied to the bolt. The bearing pre-loading values applied at the last overhaul could not be determined due to the absence of maintenance documentation.
- ❐ the presence of manganese sulphide in a highly-loaded area of the bolt. The presence of this sulphide may have generated a high stress concentration factor, leading to a local increase in stress level.

The tests and research performed as part of this investigation show that the blade pre-load bolt was formed from steel whose microstructure and composition were not optimal with respect to fatigue strength. However, the unique character of this failure, more than 50 years after the part entered service, means it is unlikely that the amount, distribution or size of the inclusions or the sulphur content in the bolt contributed to the accident.

3.2 Retaining of maintenance documents

During the investigation it was not possible to determine the actions carried out during the overhaul of the propeller as the maintenance documents had been destroyed. The destruction of these documents by the maintenance workshop which had carried out this overhaul complied with the regulatory requirements of the EASA which is to retain documents for three years following the work. These requirements exceed those defined in ICAO Annex 6 which requires that documents are retained for one year only.

This absence of traceability had already been identified during an AAIB[14] investigation into an engine failure on a Cessna 152[15] where the documents concerning the engine overhaul had been destroyed. The following recommendation was made at that time: "It is recommended that the European Aviation Safety Agency (EASA) amend EASA Part 145 (and Part M as necessary) to require that maintenance and overhaul records that are referred to in airframe, engine and propeller log books, and component record cards, are deemed to be part of that log book or record card and are retained until the aircraft, engine, propeller or component has been destroyed or permanently removed from service".

The EASA considered at the time that this corresponded to "*more paper kept for a longer period, without benefiting safety*".

(14) Air Accidents Investigation Branch

(15) https://assets.publishing.service.gov.uk/media/5422ef3de5274a1317000271/Reims_Cessna_F152__G-BHCP_1-08.pdf

4 - RECOMMENDATIONS

Note: in accordance with the provisions of Article 17.3 of Regulation No. 996/2010 of the European Parliament and of the Council of 20 October 2010 on the investigation and prevention of accidents and incidents in civil aviation, a safety recommendation in no case creates a presumption of fault or liability in an accident, serious incident or incident. The recipients of safety recommendations report to the authority in charge of safety investigations that have issued them, on the measures taken or being studied for their implementation, as provided for in Article 18 of the aforementioned regulation.

The left propeller of I-MLVT had undergone a general overhaul in June 2009. During this overhaul, the bearing pre-loading values were measured and recorded in the detailed maintenance documents kept by the maintenance organisation. As this organisation had decided to no longer maintain this type of propeller, it destroyed this documentation in July 2012 in accordance with Part 145 which requires these documents to be kept for three years. Consequently, it was not possible to compare the pre-loading values of the blade bearings measured during maintenance with the values measured during the examination after the accident, nor to have the findings from the magnetic particle inspection of the blade No 2 pre-load bolt.

In addition, this minimum archiving period of three years can be shorter than the inspection intervals which thus allows commercial air transport aircraft to fly with major components for which the background data has been destroyed.

The discussions that the BEA was able to have with the maintenance organisations did not reveal any difficulty with extending the three-year archiving period for these documents. This seems to be the practice in certain organisations already.

Consequently, the BEA recommends that:

- **EASA modifies Part 145 (and Part M as necessary) to require the maintenance organisation or the operator to keep a copy of all the detailed maintenance records and all the associated maintenance data until this data is superseded by equivalent new data or for a sufficiently long period to reduce the risk of useful data being lost. [Recommendation FRAN-2018-001]**

- **ICAO modifies Annex 6 to require the maintenance organisation or the operator to keep a copy of all the detailed maintenance records and all the associated maintenance data until this data is superseded by equivalent new data or for a sufficiently long period to reduce the risk of useful data being lost. [Recommendation FRAN-2018-002]**