TECHNICAL NOTE

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Lightning Damage of Bearing Surfaces in Turboprop Aircraft Engines

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ABSTRACT: During the servicing of turboprop engines from aircraft which had reportedly sustained lightning strikes, the No. 5 main bearing from Pratt and Whitney, Type PT-6A engines, was often found to be pitted on its bearing surfaces to a degree that required replacement. This bearing is located deep inside the engine housing and is preceded by the No. 6 propeller shaft bearing at the front of the engine casing. Microscopic examination of the pits in the rolling contact surfaces of the examined No. 5 bearings appeared to show a wear pattern similar to that obtained on bearing surfaces by delamination during mechanical wear. When examined at high magnifications in the scanning electron microscope (SEM), it was found that the brightly reflecting bases of many of the pits had a dendritic structure and striations as a result of molten metal flow. Sectioned views through several pits confirmed that the metal base portions of these pits had indeed been remelted. The only energetics that could have accounted for this type of structure in pitted bearing surfaces was rapid melting and cooling by intense electric discharges through very small contact areas in mating bearing surfaces.

KEYWORDS: engineering, lightning, aircraft, microscopy, aircraft engine bearing failure, scanning electron microscopy, surface pitting, delamination in wear surfaces, dendritic crystal growth

During the course of an investigation of several years duration, the No. 5 main reduction gear bearing (RGB) components from five Pratt & Whitney, Type PT-6A, turboprop engines were examined. Before these engines had been pulled down and serviced, there had been confirmed lightning strikes by the pilots of four of the aircraft, but not by the pilot of the fifth aircraft. However, when all five of the No. 5 main bearings were examined, they all possessed similar wear patterns.

Further, there appeared to be no time frame as to when these bearings failed, since service hours of engine operation to bearing failure varied from 200 h to the regular engine service at 1000 h.

One of the puzzling features of the observed bearing damage was that it occurred, with one exception, only in the main reduction gear bearing, which is the No. 5 main bearing in this particular type of aircraft engine. This bearing is located approximately 30 cm (12 in.) inside the engine casing from where the propeller shaft exits the engine. Immediately inside the engine casing the propeller shaft is carried by a 15-cm (6-in.) diameter ball bearing, No.

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6. Between Nos. 6 and 5 bearings the drive shaft is coupled together with a splined metal union. Thus, for the damage to No. 5 bearings to have resulted from electrical discharges, the electric current would have to had traveled from the propeller along the propeller shaft and past No. 6 bearing to No. 5 bearing where the final heavy electric discharge occurred. This current path is contrary to the general theory that lightning discharges flow over the surfaces of aircraft, and not through internal components [*1,2*].

Because of the improbable situation that lightning discharges could have been responsible for pitting and surface blemishing of No. 5 bearings, attention was directed towards their mechanical breakdown. Under direct observation the degraded bearing surfaces did, in fact, appear to have suffered surface spall. This type of failure is common in bearings that have suffered a delamination within the surface during wear [*3*].

It is the purpose of this paper to report the findings of a detailed study of surface damaged No. 5 bearings, and how the cause of this damage can be ascertained.

Materials and Methods

Two views of a typical No. 5 main bearing from a Pratt and Whitney PT-6A turboprop engine are shown in Figs. 1 and 2. The bearing consists of an inner race, which is part of the reduction gear housing, an outer race machined into its own housing, twenty alloy steel rollers, and a copper-based alloy cage to position the rollers equally around the races.

Initially, the surfaces of the inner races and each of the rollers were observed under a stereomicroscope. Particular attention was paid to the locations of blemished rollers in their cages and to the patterning of blemish markings on the inner race surfaces. There was found to be a direct correspondence between the blemish markings on the rollers and the inner races.

After the light optical examination, selected rollers were removed from their retaining cages, and blemished areas on the inner bearing race were either replicated, or sections were cut from the reduction gear housing. The selected samples were thoroughly degreased and ultrasonically cleaned before introducing them into the scanning electron microscope (SEM). In the SEM, each sample was examined at various magnifications from ×20 to as high as ×10 000. The bulk metal and deposits in the surface pits were chemically analyzed by energy dispersive X-ray fluorescence (EDX).

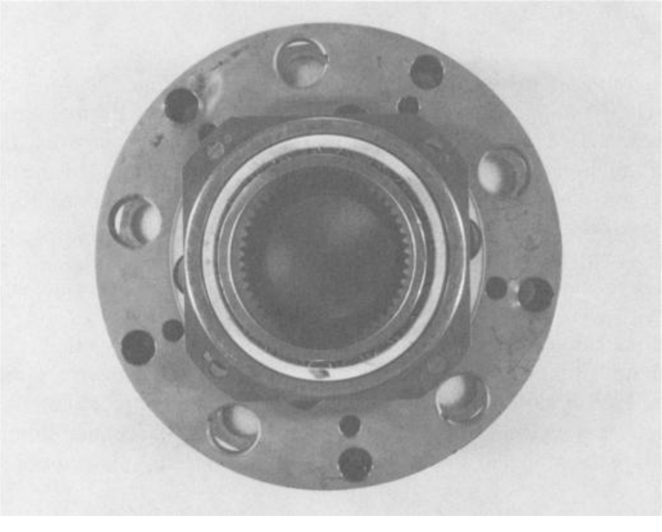

FIG. 1—*Assembled No. 5 main bearing when viewed along propeller shaft from the propeller.*

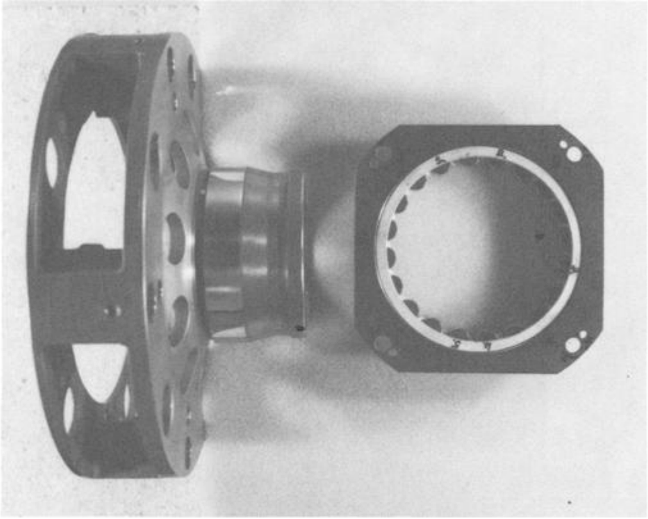

FIG. 2—*View of the separated No. 5 bearing components showing its construction.*

Results

The surface pits of interest in this investigation were generally about 200 μm in diameter, and strings of pits were spread out both in the rolling direction and lateral to the rolling direction. A blemished area containing a number of pits on a roller is shown in Fig. 3. More detailed examples of pits are shown in Figs. 4 and 5. In both these figures the rolling direction is indicated by the parallel wear marks, running from top to bottom of these figures.

These pits were partly filled with metal which was rolled level with the roller surface (see A

FIG. 3—*Surface pits in a roller showing both longitudinal and lateral placement of pits.*

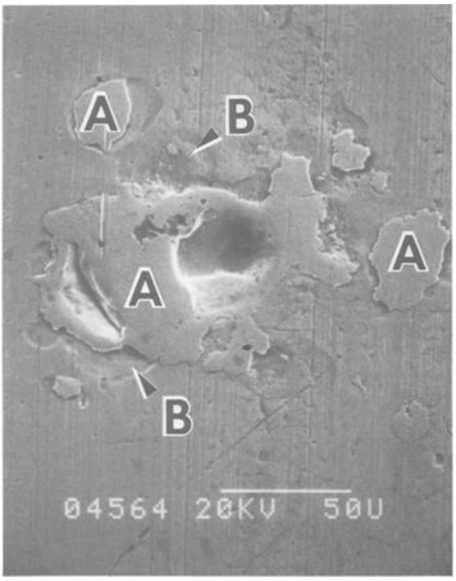

FIG. 4—*Surface pit in roller showing the pit partly filled with remelted metal and rolled in impressions in the surface.*

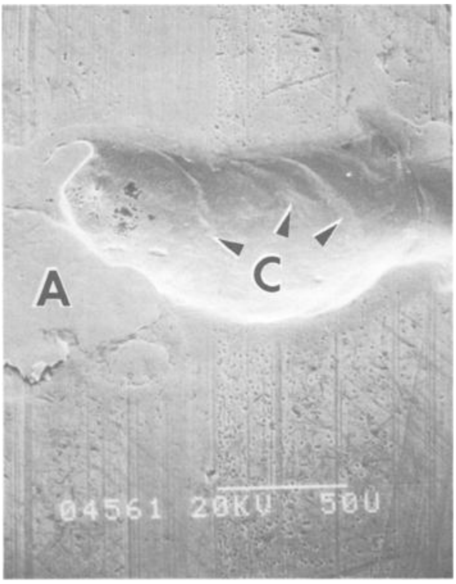

FIG. 5—*The brightly reflecting base of a roller surface pit showing flow marks.*

in Figs. 4 and 5), and sometimes this extraneous metal was indented into the roller surface from the periphery of the pit, for example, b, in Fig. 4.

X-ray spectral data from both the external roller surfaces and from the metal rolled into the pit surface contained only responses from iron (Fe) and chromium (Cr). It was apparent that both the bearing metal matrix and the metal partly filling the surface pits were of the same composition.

In some of the observed pits, especially the larger (about 500 μm), and more isolated ones, there was additional surface damage in the form of micropitting (see Fig. 6) fantailing out, like a wake from a boat, behind these pits. Although these micropits were only several microns in diameter, there were many of them congregated at various surface locations, and the resulting blemished surface was often visible to the naked eye.

Sometimes the exposed pit bottom was relatively dull and had a matt appearance when viewed under the optical microscope. In other pits, the pit bottom appeared bright and highly reflecting. Such a pit is shown in Fig. 5. In addition to being highly reflecting, this type of pit had "flow" markings along their bases, as indicated by C in Fig. 5.

At low magnification, that is, less than ×1000, there was no indication of the true structure of these highly reflecting pit bases. Actually, from the flow markings in these pits it appeared that metal in excess of the pit volume found its way into these pits and then had been flowed along the pit bases under exceedingly high pressure. This explanation of the observed flow markings would be conducive to a mechanical failure explanation.

When viewed in the SEM at appreciably higher magnifications, that is, ×3000 to ×10 000, however, these "smooth" pit base surfaces were found to have a dendritic structure (see Fig. 7), which was characteristic of a solid metal surface which had been rapidly cooled from the melt (liquid phase).

Additional data to support the conclusion that the base walls of these pits had been molten were obtained by cutting one of the pitted rollers through a pitted region and then grinding, polishing, and etching the exposed metal section. A typical SEM of the metal structure for about 15 μm below a pit base surface is shown in Fig. 8. This figure shows the pit base surface had been melted and solidified for an average depth of 3 μm. The metal structure immediately below the solidified surface had also been thermally changed to an additional depth of 10 μm, before the typical martensitic structure of this bearing alloy became apparent.

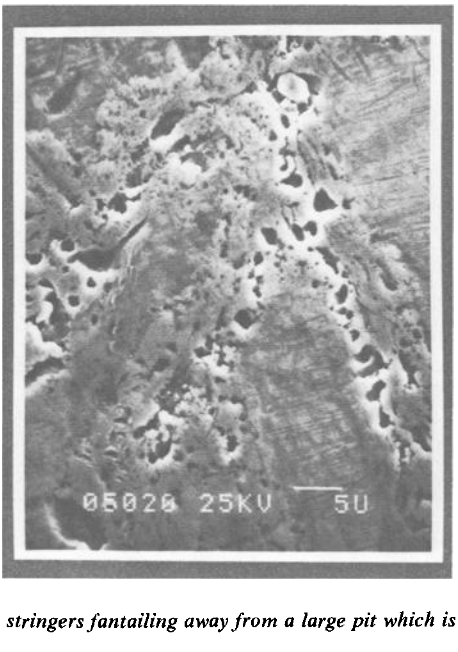

FIG. 6—*Micropit stringers fantailing away from a large pit which is out of view at top.*

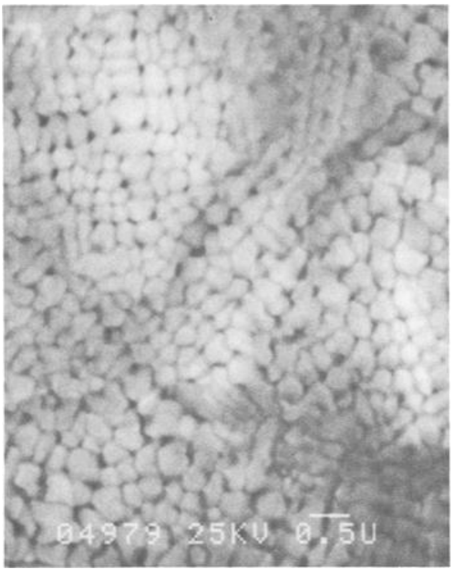

FIG. 7—*Dendritic crystal growth in the brightly reflecting base surface of a pit similar to that shown in Fig. 5.*

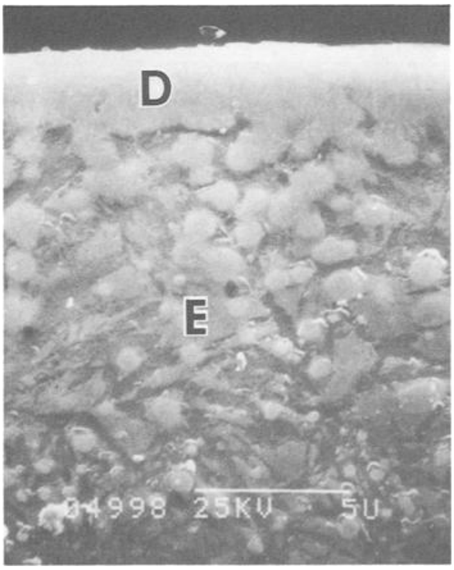

FIG. 8—*Polished and etched section through the base of a surface pit.* D *is the dendritic layer and* E *is thermally altered alloy.*

Discussion

Although the macro appearance of pits and blemished areas in the contact surfaces of these roller bearings had the appearance of mechanical breakdown and wear, the results do not support this failure mode. It would be easy to conclude that the bearing surfaces had delaminated and that separated metal particles had been pressed into other parts of the surface causing the observed patterns. However, this mode of failure was not supported when the refined data were considered. The data of particular interest were the dendritic crystal growth in the bases of pits and the thermally changed layers into the metal from these surfaces.

The only mechanism that fits these data is one in which an exceedingly large amount of energy is released in a minute volume and for a very short period of time. The type of energetics that fits this pattern is electrical discharges, and the most probable source of the electricity that produced the discharges was lightning strikes to the five aircraft. Only the pilot of one of these five aircraft had not reported a lightning strike, and it is quite probable that his aircraft could have been struck without his being aware of it.

Close examination of the metal fill in surface pits revealed that it could also have been in a molten state at one point in time. What appears to have been the process for the creation of this metal deposit in pitted areas was one of volatilization of metal in the surface, with the subsequent formation of pits and this pit formation was followed by the very rapid condensation of metal vapor. It is to be remembered that the electrical discharge phenomenon was occurring in a very confined space and in a nonoxidizing atmosphere: these bearings were running in oil which would have excluded air from the bearing surfaces. The process is analogous to spark machining of metals, except in the present situation the removed metal could not escape and was rolled back into the bearing surfaces.

To obtain dendritic crystal growth from the melt, a temperature gradient must be maintained between the liquid and solid metal. If the liquid metal is supercooled [*4*], it can take up the heat of solidification and thus allow continuous growth of the solid metal. Under these conditions the heat transfer is very rapid, and from the dendrite spacing in the solidified base metal the average cooling rate was computed to be 10^7°C/s. Experiments of Alexander and Rhines [*5*] showed that the supercooling of liquid metal could be caused by a change in composition of the alloy. Cross-sectional data from No. 5 bearing rollers showed chemical compositional changes had occurred in the pit base surfaces and these changes could have been directly associated with supercooling the liquid metal and the resultant dendritic crystal growth.

When the cause of surface pitting and breakdown needs to be determined, one needs to observe carefully the bases of surface pits with a stereomicroscope. If the bases present a mirror-like appearance, then the cause of these pits is almost certainly high intensity electrical melting and rapid solidification.

References

[*1*] Fisher, F. A. and Plumer, J. A., "Lightning Protection of Aircraft," prepared for Aerospace Safety Research and Data Institute, NASA Lewis Research Center N78-11024-11041, Oct. 1977.

[*2*] Plumer, J. A. and Robb, J. D., "The Direct Effects of Lightning on Aircraft," *I.E.E.E. Transactions on Electromagnetic Compatibility*, Vol. EMC-24, No. 2, May 1982, pp. 158-172.

[*3*] Abrahamson, E. P., II, Jahanmir, S., Colling, D. A., and Suh, N. P., "Failure by Delamination During Wear," *Scanning Electron Microscopy/1974* (Part IV), pp. 890-892.

[*4*] Martius, U. M., "Solidification of Metals," *Progress in Metal Physics*, Vol. 5, 1954, pp. 279-309.

[*5*] Alexander, B. H. and Rhines, F. N., "Dendritic Crystallization of Alloys," *Journal of Metals*, Vol. 188, Oct. 1950, pp. 1267-1273.

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