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Failure of a crankshaft of an aeroengine: A contribution for an accident investigation

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ABSTRACT

The objective of this work is to determine the main cause of failure of a crankshaft from an ULM airplane aeroengine. The core of this paper is focused in the analysis of the damage mechanisms which were in the base of a catastrophic failure of the crankpin journal. Based on a preliminary observation of the fracture surface, there are clear evidences of a fatigue process as both beach and striation marks have been identified. The judicious characterization of the failing mechanism, including the identification of the crack initiation site and the assessment of the crack propagation rate, is of paramount importance to support the investigation of this aircraft accident. In this context, an exhaustive observation of the fracture surface by means of optical and electronic microscopic techniques, in parallel with microstructural examinations, were carried out as determinant information for the correct assessment of the contributive causes to this accident.

1. Introduction

During the last years, a considerable effort has been addressed towards the application of methodological scientific approaches regarding the investigation of aircraft accidents resulting from the failure of structural or mechanical components. Distinct promoting factors can be in the base of this type of occurrences, like an inadequate design of the component, an incorrect manufacturing procedure, any eventual intrinsic defect in the material or a misjudged operation procedure of the aircraft (i.e., beyond the design limits). On the other hand, aircrafts typically have to withstand stringent operational requirements which force aeronautical components to severe working conditions, such as high loading factors, cyclic and time dependent damage mechanisms due to creep-fatigue, steep temperature gradients (including elevated temperature environments), corrosion under stress, vibrations and others. As a consequence, deficiencies always arise which makes it necessary to assess the significance of the defect with respect to its impact in terms of the airworthiness requirements, and even on an economic perspective, related with the normal operation of aircrafts [1]. Moreover, a failure investigation and subsequent analysis should determine the primary cause of failure aiming at determining adequate corrective actions that will prevent similar failures.

In the particular case of the present paper, efforts have been made to investigate the contributory factors for the failure of a crankpin journal of an ultralight airplane (ULM) engine. This crankpin belongs to a crankshaft of a four cylinder reciprocating engine. The crankshaft is one of the most important parts in an engine since it bears large cyclic loads during the working process. This component has typically a complex geometry, being responsible for the conversion of the

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reciprocating linear displacement of the pistons to a rotary movement of the power shaft. The need for a smooth operation in the base of the conversion between these two movements implies a very precise alignment of all components which, in turn, must withstand severe cyclic loads as consequence of the gas combustion in the combustion chamber of the engine. These strict operation conditions may promote distinct forms of failing mechanisms which are most of the times responsible for the premature catastrophic failures of crankshafts. In particular, fatigue is the leading ruin process in the most part of failures in crankshafts, which are typically caused by bending loads and/or torsional loads on the journals fillets [2,3]. On the other hand, misalignments, even on a small extent, can produce very high stress concentration regions and therefore acting as triggering factor for the onset of a fatigue process.

With increasing of rotational speed and power density, bending fatigue fracture becomes the main failure mode of crankshafts [4]. The crankshaft, in a normal situation, is subjected to torsion and bending loads. Generally the loads application needs to be analyzed considering two main scenarios [5]:

- Failure may occur at the position of maximum bending; this may be at the center of the crankshaft or at either end. In such a condition the failure is due to bending and the pressure in the cylinder is maximal;
- The crankshaft may fail due to torsion, so the crankshaft needs to be checked for torsion loads at the position of maximal torsion. The pressure at this position is a combination of a fraction of maximal bending pressure and the maximal engine torque.

In order for fatigue to occur, a cyclic tensile stress and a crack initiation site are necessary. The crankshafts run with harmonic torsion combined with cyclic bending stress due to the loads of the cylinder pressure transmitted from the pistons and connecting rods – to which inertia loads have to be added. Although crankshafts are generally designed with high safety margins in order not to exceed the fatigue strength of the material, high cyclic loading and local stress concentration may lead to the formation and growth of cracks even when the fatigue strength is not exceeded in terms of average values [2]. One critical spot in crankshafts is the interface region between the crankpin journals and the webs, where stress concentration issues are normally mitigated through a fillet with an adequate geometry.

For this purpose, a fillet rolling technology has been widely used for many years [4]. The radius itself reduces the stress in these critical areas, but since the fillets in most cases are rolled, this also has a beneficial effect due to the induced compressive residual stress in the surface, which prevents cracks from forming. It is difficult though to account for the exact stress distribution in the fillet region as this depends on several factors.

The main objective of this work is to undertake the analysis of the damage mechanisms which promoted the catastrophic failure of the aforementioned crankpin journal aiming at identifying the crack initiation site and characterizing the main features of the fracture surface. This qualitative information is crucial for assessing the loading conditions that promoted the fatigue process in order to support the conclusions in the report emanated by the air safety authority having as main premise the avoidance of a similar hazardous situation in the future.

2. Case study

The failed crankshaft presented in this work belongs to a four stroke, four cylinder liquid air cooled engine of an ultralight airplane that had an accident. The nominal power output of this engine is 73.5 kW at 5800 rpm. At the time of the accident, the engine had a total of 996 h of reported service. According to the technical specifications provided by the manufacturer, this engine's TBO (Time Between Overhauls) is 2000 h. The failed component is depicted in Fig. 1 where it is possible to visualize the fracture zone in the interface between the crankpin journal #2 and the counterweight. Each of the crankpin journals has been press-fit into the web sections in the opposite end to the counterweight.

Fig. 2 shows each side of the failed crankpin journal. These images are clear about a perpendicular fracture surface pattern regarding the longitudinal axis of the crankpin journal. The journal was found to have an extensive crack running from the

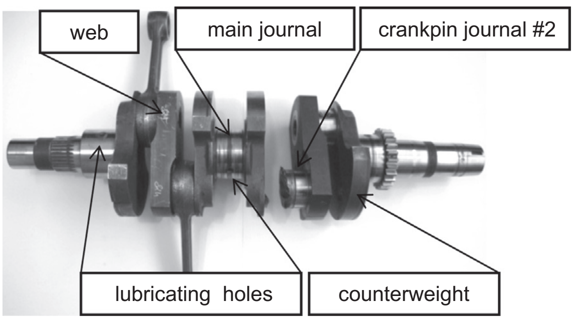

Fig. 1. Image of the failed crankshaft. Fracture has occurred in crankpin #2.