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A HYBRID PROBABILISTIC MODEL FOR PROGNOSTIC

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Abstract. In this paper, a hybrid probabilistic model for prognostic performance evaluation on repairable systems is proposed. This model allows to evaluate the expectation of failed components at any predetermined inspection times and over the system service life. An aeronautical application is addressed in the context of aircraft structural fatigue damage preventive maintenance. A comparative study between the hybrid model and the crude Monte Carlo method is carried out showing the efficiency of the proposed model. The expected number of failed structural components is computed at scheduled inspections and over aircraft lifetimes. The impact on the distribution of the failure threshold as well as the initial crack length one is analyzed and consequences on structural prognostic are shown. Comparative results on computing time show that the hybrid model is much less time consuming than Monte Carlo simulations. The proposed hybrid approach is flexible to use and useful to compare different maintenance policies based on both scheduled inspections or sensing SHM systems. It is therefore a relevant tool for prognosis and maintenance decision-making.

Keywords. Probabilistic model, prognostic, structural maintenance, fatigue damage

1 Introduction

For a repairable system, failures and maintenances can be considered as recurrent events. The theory of recurrent events modelling is usually based on the counting processes theory (see [1, 2]). A presentation of these processes in the reliability context is exposed in the reference books (see [3, 4, 5]). Moreover, a very general class of recurrent event models that includes most of the useful reliability models have been introduced by these authors (see [6, 7]). Maintenance process modelling is a major issue common to many industries. By contributing through its effect to ageing management, maintenance plays a vital role in risk management and is a determinant key of system performance. Many models have been developed to assess the maintenance impact on repairable ageing system or component, and optimize maintenance sequence operations.

Our paper proposes a useful probabilistic model allowing to compute the probability of failure of a system made with identical components and deduce the expectation of failed components over the system service life according to a maintenance strategy. Recurrent analytical formulas are able to provide the component probability of failure at any cycle of its life and over its lifetime.

An application in the aeronautical field is developed in the context of structural damage tolerance maintenance approach. The current philosophy in aircraft maintenance is based on scheduled regular inspections at intervals prescribed by the manufacturer. This preventive maintenance, also called damage tolerance approach, is typically followed in aircraft structures (see [8, 9]). Once an aircraft enters service, it is subject to a sequence of cycles. A cycle includes the flight followed by a landing. During the flight phase, the fuselage structure undergoes pressurization and depressurization. This type of cyclic loading can cause crack initiation and growth, which can lead to failure (see [10]). Typically, maintenance intervals for aircrafts are determined so that no crack can grow to a critical size before the next inspection (see [11, 12]). In this approach, the structure is designed to tolerate small level of damage (see [13]). Therefore, only large damages need to be repaired. Unfortunately, regular frequent inspections result in high maintenance costs as the intervals between inspections are kept short due to a conservative mind-set and parts may be replaced well before failure.

Aircraft maintenance costs can be substantially reduced by using structural health monitoring (SHM) systems. Such SHM techniques have been the object of considerable research during the last two decades and are now ready for use in preventive condition-based maintenance. Active sensing SHM systems can be installed on aircraft using on-board sensors and actuators to monitor the damage state in real time (see [14, 15]). Data from the sensors can be combined with information processing algorithms based on probability or fuzzy logic to guide the maintenance actions (see [16, 17, 18, 19, 20, 21]). Many investigations are addressed on SHM system based on ultrasonic guided waves (see [22, 23, 24, 25]). Acousto-ultrasonic guided waves are generated via the use of piezoelectric actuators which can also operate as sensors. Each sensor-actuator pair forms a distinct signal propagation

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