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Identification of optimal preventive maintenance decisions for composite components

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Abstract

This research proposes a decision support tool which identifies cost-optimal maintenance decisions for a given planning period. Simultaneously, the reliability state of the component is kept at or below a given reliability threshold: a failure limit policy applies. The tool is developed to support repair-or-replacement decision making for composite components likely to suffer impact damage. As a core part of the tool, a cost minimization problem is defined and solved using a search tree algorithm with heuristic constraints. Application to a case study which utilizes historical damage data and subsequent simulation shows the potential of the tool to identify cost-minimal maintenance decisions. The decision support tool is capable of incorporating a wide range of parameters to study preventive maintenance decision making in depth.

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Keywords: Aircraft maintenance; composites; decision support; preventive maintenance optimization

1. Introduction

The latest generation of wide-body transport aircraft shows a significant increase in composite structures, as evidenced in the Boeing B787 and the Airbus A350 XWB. The B787 is the first commercial aircraft to use Carbon Fiber Reinforced Plastic (CFRP) for the entire pressurized fuselage (Dhanisetty et al., 2016). Besides the fuselage, B787 uses composites for the windows, wings, tails and stabilizers, resulting in approximately 50 % share of the total weight (Zhao et al., 2014). The introduction of composites into primary structures brings the advantage of

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weight savings and therefore potential for generating fuel savings for airlines. However, compared to the decades-long experience with aluminum structures, there is a relative lack of experience of using and maintaining composites in these primary aircraft structures. In particular, the frequency, severity and rectification of impact damage are difficult to forecast, as limited historical data is available. This poses a challenge with respect to ensuring aircraft airworthiness over longer periods of time. Consequently, conservative approaches are adopted to ensure safe aircraft operations. In addition, regulatory requirements on maintenance stipulate the implementation of reliability programs to monitor and improve aircraft reliability over time.

Within the research domain of reliability engineering, significant amounts of research have been performed under the assumption of non-repairable systems, as noted by previous authors (Crow, 1990; Love and Guo, 1993; Weckman et al., 2001). However, this assumption is not valid for composite systems, which can be characterized as being repairable. When considering existing research on repairable systems (Chen and Feldman, 1997; Doostparast et al., 2014; Jayabalan and Chaudhuri, 1992a; Jayabalan and Chaudhuri, 1992b; Lie and Chun, 1986; Love and Guo, 1996; Nguyen and Murthy, 1981), it can be generally noted that strong assumptions are made when connecting reliability output with maintenance planning and control. Costs are sometimes treated as a continuous function rather than a discrete time event, which does for instance not match with composite impact damage events. Frequently, repairs are assumed to bring the component back to an 'as-good-as-new' state, which may not be true for particular composite impact damage failure modes. Furthermore, maintenance planning solutions are often obtained using optimization techniques which only estimate the solution area (as shown in (Doostparast et al., 2014; Jayabalan and Chaudhuri, 1992a; Jayabalan and Chaudhuri, 1992b)). Combinatorial, precise calculations are avoided due to the extensive computational effort involved in such an approach. Taking into account the mismatch between the aforementioned strong assumptions and real-life maintenance applications as well as the use of imprecise solution methods, a lack of application of existing optimization models for preventive maintenance can be distinguished in practice (Dekker, 1996).

Given these factors, this research aims to develop a practical decision supporting tool, which identifies cost-optimal maintenance decisions for a given planning period. Simultaneously, the reliability state of the component is kept at or below a given reliability threshold. The tool applies to composite components likely to suffer impact damage.

In Section 2, existing techniques to perform reliability analysis for composite components are investigated, together with uptake in preventive maintenance decision making. Subsequently, Section 3 describes how failure of repairable components is modelled using a Generalized Renewal Process (GRP). Furthermore, modelling of maintenance cost as discrete time events is described, which allows to realistically represent practical conditions. Reliability and cost serve as inputs towards optimization of long-term planning problems, where application of a Search Tree algorithm allows to find a precise combinatorial solution. In order to reduce the computational effort and solve long term planning problems, realistic heuristic constraints are identified and applied. The reliability, cost and optimization models are implemented in a decision support tool. In Section 4, a numerical case study has been devised on the basis of simulated damages generated by a Monte Carlo approach. Results are presented and analyzed. Sensitivity analysis is employed to present the impact of selected parameters on the resulting maintenance costs. Finally, conclusions and recommendations for future research are given.

2. Theoretical context

Preventive maintenance (PM) is a scheduled maintenance event, which triggers a planned maintenance task. It is often assumed that a component is replaced at a PM maintenance event. However, for repairable components, such as composites, both types of maintenance action (repair or replacement) can be feasible. The aim of the preventive maintenance is to improve the reliability state of the component. Several subpolicies can be identified as part of preventive maintenance; in this paper, the focus is on a failure limit policy (Pham and Wang, 1996), where the reliability of a given component must not drop below a given threshold.

To apply a failure limit policy towards maintenance planning, it is imperative to estimate component reliability. Many research efforts have focused on non-repairable systems (Crow, 1990; Love and Guo, 1993; Weckman et al., 2001). The general approach when analyzing the reliability state of a non-repairable system is to use renewal theory, which reduces the considered system to a single component [4] with only two states: operating and failed. Such a