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Reliability model for helicopter main gearbox lubrication system using influence diagrams

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ABSTRACT

The loss of oil from a helicopter main gearbox (MGB) leads to increased friction between components, a rise in component surface temperatures, and subsequent mechanical failure of gearbox components. A number of significant helicopter accidents have been caused due to such loss of lubrication. This paper presents a model to assess the reliability of helicopter MGB lubricating systems. Safety risk modeling was conducted for MGB oil system related accidents in order to analyse key failure mechanisms and the contributory factors. Thus, the dominant failure modes for lubrication systems and key contributing components were identified.

The Influence Diagram (ID) approach was then employed to investigate reliability issues of the MGB lubrication systems at the level of primary causal factors, thus systematically investigating a complex context of events, conditions, and influences that are direct triggers of the helicopter MGB lubrication system failures. The interrelationships between MGB lubrication system failure types were thus identified, and the influence of each of these factors on the overall MGB lubrication system reliability was assessed. This paper highlights parts of the HELMGOP project, sponsored by the European Aviation Safety Agency to improve helicopter main gearbox reliability.

1. Introduction

Helicopters are totally dependent on their rotor transmission (RT) systems, which provide the critical links from the engines to the main rotor, tail rotor and ancillary systems. These components are highly loaded and must be manufactured to a high degree of accuracy; the lack of redundancy implies that this is a ‘series-chain’ system [1,2].

These RT systems are in turn totally dependent on a functioning lubrication system. The loss of oil from a helicopter main gearbox (MGB), which is a central system within a helicopter, will lead to mechanical failure of the gearbox components. Current certification requirements for Category A helicopters (large helicopters) require that gearboxes which use pressurized lubrication systems must show a capability to continue operation for a period of 30 min after suffering a loss of oil [3]. However, this has not always been met in service with current designs. Many Category A helicopters fly sectors which are over one hour in duration and in the event of a main gearbox loss of oil could require a forced landing over hostile terrain. There have been a number of significant accidents involving the loss of helicopters due to a failure of the Main gearbox lubrication system. A particular case in point was the crash of a large helicopter off the coast of Newfoundland in 2009 [4]. This paper summarizes parts of the Helicopter Main Gearbox Oil Performance Optimization (HELMGOP) project. This research program [5] was launched in 2011 by the European Aviation Safety Agency in response to the safety recommendation from the aforementioned Newfoundland accident.

This paper explains the use of Influence Diagrams (ID) to supplement the traditional Fault or Event Trees. Analysis of causal factors will often allow a Fault Tree model to be produced as far as the data allow. However there are many factors that relate to management, organization and culture that cannot be clearly included as “events”. The same can also be said for many physical degradation processes which affect systems (including gearboxes), for instance; wear, corrosion and fatigue. The actual failure itself may be an “event”, but there is a whole process that leads up to it, with many different influences.

The ID approach to system reliability assessment is a detailed probabilistic safety assessment technique that represents the factors

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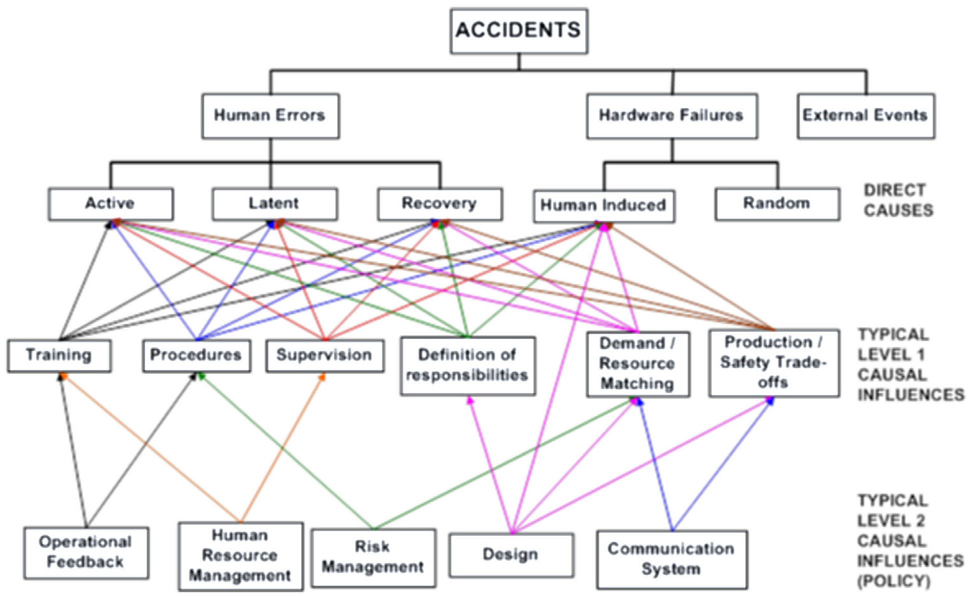

Fig. 1. Generic influence diagram model for accident causation [7].

influencing reliability of the system under study [6]. A generic model of accident causation was proposed by Embrey [7] which showed a combination of Event and Likelihood/Influences layers, see Fig. 1. This approach, entitled MACHINE[1] featured two distinct layers, namely Event layer and Likelihood (Influence) layer, hence the term Event-likelihood model [8].

As Fig. 1 indicates, the ID concept is introduced to tackle multi-dimensional complex problems which involve internal mutual interference of factors that collectively produce a single overall event. It works to link qualitative description of complex technical problems, and their quantitative specifications. This approach "can serve the three levels of specification of relation, function, and number" [7] of involved factors, and it works in both deterministic and probabilistic cases.

Hokstad et al. [9,10] and Herrera et al. [11] used the ID approach to assess risks associated with operating helicopters over the North Sea. The approach, with its ability to represent both technical and management issues, can be used for assessing reliabilities of a wide variety of systems. A further example is in the domain of Air traffic management in which an Integrated Risk Picture was created by Eurocontrol in 2006 [12]. This used a combination of Fault tree analysis and ID to estimate risk due to errors that can influence five different accident types. More details on the development and use of IDs are available within these references. Detailed ID mathematical model is given by Embrey [7] for further reference as well.

The MGB lubrication system designs of various helicopter types are different with respect to component layout, structures, redundancy and detailed performance specifications. This variation in designs emphasizes the need for a generic model to accommodate the differences between designs. This study introduces such a generic ID component-based model. The approach taken allows more flexibility than other techniques that are available e.g. fault tree analysis, and can easily be reconfigured in the light of new information or data.

2. Methodology

This paper reports on a method for assessing the reliability of pressurized lubrication systems, and summarizes the dominant

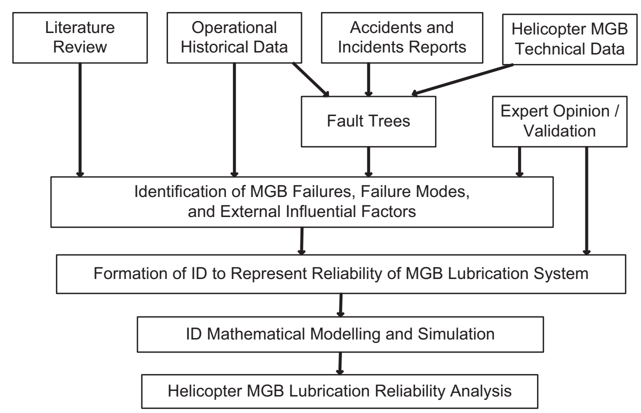

Fig. 2. Research methodology – sequence of activities.

failure modes. The Influence Diagram approach was applied to investigate the reliability of the MGB pressurized lubrication system, and the role each sub-system component may play to influence the overall reliability. Three main activities are conducted and discussed within this research and Fig. 2 illustrates the sequence of the work. Results obtained from these activities are discussed to set the basis for both prevention and mitigation techniques in regard to MGB lubrication system failure.

(i) Literature review covering aspects of MGB design and architecture, lubrication, failure diagnostics and prognostics, reliability and testing.
(ii) Determination of MGB lubrication systems failure triggers and failure modes, and other failure contributing factors through fault trees analysis, and by consulting industry experts.
(iii) Investigation of the MGB lubrication system reliability at the sub-system level using ID concept.

Within the current research, an ID model is formulated to evaluate the effect of different design and maintenance factors on the overall performance of the MGB oil system. The aim is to introduce a generic tool, based on authenticated evidence, which can be used to evaluate the helicopter MGB lubrication system at a given set of inputs. A failure is considered to have occurred if any

[1] Model of Accident Causation using Hierarchical Influence Network Elicitation.