Engine gearbox prognostics based on vibration analysis and in-line oil debris monitoring: technical and economical merits

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Our research group of students would be glad to participate to the 2009 PHM Society Conference and present the study which is being performed in fulfillment of the requirements of the High Polytechnic School, a joint initiative of the Polytechnic Institutes of Milan and Turin.

Our first aim is to receive specific suggestions on ways to improve the work performed up to now and get directions on how to best conclude our study. In addition to useful recommendations that we will obtain from a presentation of our study in front of an audience comprised of qualified experts from the academia and the industry, we hope to establish contacts with other students active on PHM, which might lead to an exchange of our experience in this area and to possible future cooperation.

Finally, we are positively sure that we would have the possibility to learn about the most recent progresses on prognostics in order to include them in our project.

INTRODUCTION

Gearboxes are used in the aircraft engines with two main purposes: as a mean to drive several accessories (lube oil, fuel and hydraulic fluid pumps, electrical generators), and as a speed reducer between engine and propeller shafts in turboprops and helicopters. Whichever their function, gearboxes are a critical component, for their failure would severely impair the engine operation and in most cases lead to the engine shutdown. The criticality of gearboxes in ensuring the correct engine operation led the gearbox manufacturers to seek ways for determining the gearbox health in order to reduce to a minimum the risk of in-flight failures. Most of the risk mitigation actions consist of ensuring the cleanliness of the lubricating oil and of performing periodical inspections aimed at detecting possible flaws in the gears. Inspections are typically performed with a boroscope, are time consuming and the probability of positively detecting flaws is affected by several factors, including the ability of the person executing the test. At the same time the cleanliness of the lubricating oil is ensured by a periodical replacement of the oil and by checking the accumulation of debris on a magnetic chip detector. As for the boroscopic inspection, the verification of the magnetic chip detector is a time consuming periodical maintenance action contributing to the overall life-cycle-cost.

1. PROBLEM ADDRESSED

Finding a reliable prognostic technique able to detect the precursors of a gearbox failure would greatly improve the gearbox maintainability, actually moving from a scheduled maintenance to a condition based maintenance philosophy. The present work stems from a basic R&D activity carried out by the engine manufacturer Avio that performed extensive tests on gearboxes taken from its production line in which defects were created on purpose to verify the variations of the vibration signature, and in which oil debris were injected to test a new device aimed at continuous in-line monitoring of the lubricating oil contamination level. The study which is being carried out aims at determining if the implementation of a gearbox prognostic system based on vibration analysis and in-line oil debris monitoring will in the end lead to a reduction of the gearbox life-cycle cost and should thus be recommended for installation on the engine gearboxes.

In order to provide an answer to this point, the study is first addressing the following main issues:

- Analysis of the devices used to detect the gearbox health, their accuracies and error sources
- Analysis of the data collected by Avio in their test campaign in order to evaluate the probability density function for the detection of a gearbox

degradation; about 160 GB of experimental data are available

- Assessment of the present failure rates of an engine garbox
- Reliability analysis of failure rate data and analysis on usage of statistic prognostic for residual life estimation correction
- Definition of an algorithm able to recognize the degradation pattern and to reliably predict the remaining useful life and evaluation of the probability of false alarms and missed failures
- Assessment of the costs associated with a gearbox failure while in service (costs determined by in-flight shut down, aborted takeoff, unscheduled engine removal, gearbox removal and replacement, etc.) in standard configuration
- Assessment of the costs associated with a gearbox failure while in service (costs determined by in-flight shut down, aborted takeoff, unscheduled engine removal, gearbox removal and replacement, etc.) with Electronic Prognostic Unit

Following this first part, the study will evaluate the economical merit of implementing a prognostic system on an engine gearbox considering two different scenarios:

a) A gearbox of an engine for a commercial aircraft

b) A gearbox of an engine for a military aircraft

For both scenarios, a logistic support system is defined and the number of spare parts to be kept in stock at previously defined maintenance bases is determined for the two cases of conventional gearboxes and of gearboxes equipped with a prognostic system. A 30 years life for the engine is assumed and the different maintenance policies and requirements for commercial and military aircraft are duly considered.

2. EXPECTED RESULTS

The expected result of the study is to find out if the costs associated with the implementation of a prognostic system based on state-of-art technology on an engine gearbox, which includes hardware and development costs, will be offset by the reduction of the maintenance costs and by the reduction of costly mishaps leading to unscheduled engine removals. Moreover it will be also considered whether the prognostic system would facilitate to implement a logistic system addressed on a Just in Time approach so that it would be possible to reduce costs related to spare parts to be kept in stock.

On the economic point of view, activities carried out since now demonstrate that costs associated with a gearbox failure while in service when considering a gearbox of an engine for a commercial aircraft accounts for 10 times costs related to a gearbox of an engine for military aircraft. This huge difference is essentially related to the different Engine Flight Hours (EHF) respectively equal to 125’000 and 7’500 on 25 years as average gearbox lifecycle.

This study is being performed in fulfillment of the requirements of the Alta Scuola Politecnica (High Polytechnic School), a jointly initiatives of the Polytechnic Institutes of Milan and Turin, Italy. The students enrolled in the Alta Scuola Politecnica carry out this project in addition to their regular studies and will be awarded a special recognition at the end of their academic program. The study started about a year ago and is due to be completed by the end of 2009. Though the work is in process, the results obtained so far are encouraging and a presentation is proposed to the Doctoral Consortium of the PHM International Conference in which the issues addressed by this study will be outlined, the relevant results will be shown and suggestions for best completing the activity will be sought.