Identification of structure-specific damage properties and its impact on improved prognosis

Alexandra Coppe[1], Nam-Ho Kim[2], and Raphael T. Haftka[3]

[1,2,3] *University of Florida, Gainesville, FL, 32611, USA*

alex.coppe@ufl.edu
nkim@ufl.edu
haftka@ufl.edu

1. PROBLEM ADDRESSED

The prediction of remaining useful life (RUL) based on damage size is inaccurate because there is wide distribution of damage growth properties between different batches of the same material and due to differences in ageing. Consequently, conservative predictions of RUL are necessarily much lower than the average. However, structural health monitoring (SHM) allows us to follow damage growth, and this should allow identification of structure-specific properties. This in turn will allow identification of the small percentage of structural elements where damage growth is fast. The objective of this research is to demonstrate that it is possible to use SHM data to narrow down the uncertainty in damage growth material properties and hence narrow down the uncertainty in RUL.

A challenge is to characterize structure-specific damage properties using noisy SHM data. Compared to manual inspections, the accuracy of SHM is still poor. Thus, how can we accurately measure damage growth with noisy and inaccurate data? Our answer is to use Bayesian techniques to take advantage of the wealth of data so as to compensate for its poor quality.

2. EXPECTED CONTRIBUTION

The problem I chose to address can be divided in three contributions that are discussed in this section. The first two are focused on prognosis and the third one on diagnosis. They are closely dependent on each other.

The first contribution is to demonstrate how to use the frequent measurements of damage growth afforded by SHM to allow us to narrow the uncertainty in the material properties that govern damage growth. The uncertainty in these properties is normally large because of variability in manufacturing and ageing of the monitored structured. A probabilistic approach using Bayesian statistics is employed to progressively improve the accuracy of predicting damage parameters under variability and error of sensor measurements. That is, we use the measurements to identify specific properties for each structure on each plane. This process can be viewed as turning every aircraft into a **flying fatigue laboratory.** In a fatigue laboratory, when many specimen are tested and each has different damage growth properties, the outcome is a wide distribution of these properties. SHM allows us to test individually each component on each airplane! The second contribution is to translate the improved knowledge of structural properties to predict more accurately the RUL in the statistical framework. Our goal here is to obtain a stratistical distribution of RUL.

The third contribution is to translate the previous contributions into a diagnosis of the structure's health state given uncertainties in measured data from SHM, uncertainties in damage parameters, and uncertainties in applied loadings. The outcome of that process will be an estimate of the probability of failure due to damage in the next flight or number of flights.

3. PROPOSED PLAN

The approach is demonstrated for a through-thickness crack in an aircraft fuselage panel which grows through cycles of pressurization and de-pressurization. To begin with, a simple damage growth model, Paris model, with two damage parameters is utilized. However, later we may move towards more advanced damage growth models, which usually come with more parameters. We will possibly consider using software like NASGRO to simulate crack growth. The ultimate application of this work would be to have actual crack growth information coming from inspection.

3.1 Identification of structure-specific damage parameters using noisy data

Using the simple Paris model we aim to demonstrate that SHM can be used to identify the damage parameters of each particular panel. Narrowing of uncertainty in damage growth parameters can narrow in turn the uncertainty in predicting remaining useful life (RUL), i.e. in prognosis.

In the original Paris model, defined in Eq. (1), there are two damage parameters, *m* and *C*.

$$\frac{da}{dN} = C(\Delta K)^m \tag{1}$$

To start with we want to consider these parameters separately and update their distribution starting from the handbook distribution (which reflects fatigue tests). The updating is done using a statistical tool called Bayesian updating defined in Eq. (2) where $P(g|m)$ is the key part called likelihood function. It is defined as the probability to have the information obtained from inspection, in this case crack growth, for a given data we want to identify, in this time the exponent parameter *m*.

$$f_{updt}(m) = \frac{P(g|m) f_{ini}(m)}{\int_{-\infty}^{+\infty} P(g|m) f_{ini}(m) dm} \tag{2}$$

The above Bayesian updating technique can be applied for both damage parameters individually. When only one parameter is updated, the other parameter is assumed to be deterministic.

However, it is well known that the two damage parameters are correlated. Thus, the next step will be updating the joint distribution of both parameters. Then we can move towards a more complicated model. There is a good chance that even if damage growth cannot be modeled accurately by Paris law with fixed C and m for all cases, the ability to tailor C and m to each damage case will be accurate enough.

3.2 Reliability-based prognosis

As mentioned before, the first step is to update the two damage parameters individually, considering the other one as known for the structure and observe the effect on prognosis compared to the prognosis obtained using the handbook distribution. We have done this and we obtained a significant improvement with respect to the initial handbook distribution.

The damage parameters are not the only distributed variables; we also need to consider the variability in loading history and its effect on RUL. All this leads us to have a probability distribution function (PDF) of RUL instead of a deterministic value. This allows us to calculate a value with given level of confidence, for example 95% confidence, and will allow us to extrapolate it to the probability of failure (PoF) in the future.

3.3 Statistical diagnosis of structure's health state

Another application of this work is to calculate the PoF of a structure more accurately. One of the interests on this is to guarantee the reliability of the structure. This can be used to justify the fact that even if SHM is not as accurate as manual inspection, it still allows us to reach a high enough level of reliability. The idea is to be able to diagnose whether a crack is stable or not, whether the structure is safe and for how many more flights..