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HISTORICAL OVERVIEW OF MODEL-ASSISTED PROBABILITY OF DETECTION (MAPOD)

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ABSTRACT

This presentation provides a brief overview of Model-assisted Probability of Detection (MAPOD), plus a historical perspective of MAPOD. This includes work by the MAPOD Working Group, sponsored by the US Air Force Research Laboratory (AFRL), National Astronautics and Space Agency (NASA), and the Federal Aviation Administration (FAA), that included multiple voluntary contributors from industry, national laboratories, and academia. Representative examples are described to address the two major classes of MAPOD which are transfer functions and full model-assisted POD. A US Air Force (USAF) example of the use of transfer functions is described in detail and the inclusion of MAPOD in the latest revision of MIL HDBK 1823A is discussed.

Keywords: model-assisted probability of detection, probability of detection, transfer functions.

NOMENCLATURE

MAPOD	model-assisted probability of detection
NDI	nondestructive inspection
NDE	nondestructive evaluation
POD	probability of detection

1. INTRODUCTION

Nondestructive inspection (NDI) is a critical component of ensuring the integrity of United States Air Force (USAF) structures and is a part of the Aircraft Structural Integrity Program (ASIP) as defined in MIL STD 1530Dc1 [1]. The capability of an NDI procedure to detect flaws of a certain size is determined using Probability of Detection (POD). The USAF uses a durability and damage tolerance approach to ensure the integrity of the structure and the POD curve is one of multiple inputs to calculate risk of structural failure as shown in Figure 1. For this reason the USAF has performed significant progress to standardize capability of known inspection procedures [2]. The published capabilities are based on POD assessments for multiple standardized inspection scenarios. However, when inspections that are not easily standardized, such as most

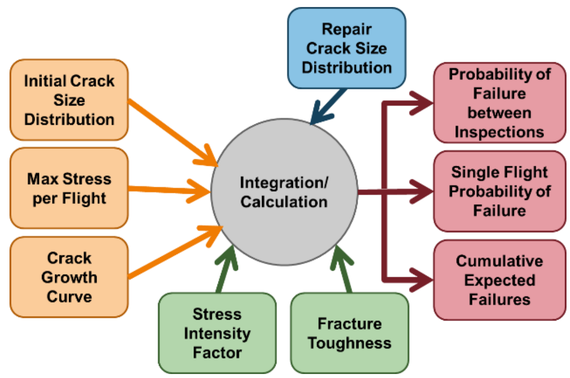

FIGURE 1: INPUTS FOR QUANTITATIVE RISK ANALYSIS

ultrasonic inspections, or when new inspections for a specific structural feature is developed, the capability of the inspection is determined using a new POD study. This is especially true if the item being inspected is safety critical. With the increased number of aging aircraft in the USAF fleet, the number of these inspections is projected to increase.

2. MIL HDBK 1823A

To provide guidance on determining the capability of an NDI procedure, the USAF publishes Military Handbook (MIL HDBK) 1823, revision A [3]. The document defines the assumptions that must be met to perform a statistically valid POD study, including the suggested number of test samples with flaws, samples without flaws, the environment in which the inspections are performed, and the need for independence between each flaw in the study. MIL HDBK 1823A is referenced by many organizations, such as NASA and the FAA, as the proper guidance to follow to perform a full POD study to give a valid POD curve and false call rate. For some inspections, the full curve is not required and alternative methods can be use.

When following the guidance of MIL HDBK 1823A, there is a number of independent samples with flaws of different sizes that are required to obtain a statistical distribution to meet the assumptions on generating the POD curve. The flaws must be the same as the type that is being detected by the NDI procedure. In other words, a POD curve for the detection of corrosion cannot be applied to the detection of fatigue cracks. In some cases, this requirement can become quite costly when each sample must include the representative structure being inspected, plus a localized grown fatigue crack in the area where the inspection is accomplished. The burden of generating these samples led to the concept of Model-assisted POD (MAPOD) to alleviate the time and cost to generate the full spectrum of flawed test articles required to determine the POD empirically.

3. MODEL ASSISTED POD

The concept of MAPOD is based on using models to streamline the determination of POD by using various simulation results to complement empirical data and reducing the number of test samples required to complete a full POD study. Two general classes of MAPOD have been defined, one using transfer functions and a second using physics-based models. The latter is sometimes referred to as a full model-assisted POD.

3.1 Transfer Function MAPOD

The motivation for a transfer function approach is to decrease the need to generate the full number of required representative defects in test samples, especially if the time and/or cost to generate the samples, the defects, or both, is relatively high. The fundamental concept would be to generate two sets of relatively simple test samples, such as simple plates or edges, one with grown defects, such as fatigue cracks, and another set with manufactured defects, such as electric discharge machined (EDM) notches. A POD assessment would be completed for these two sample sets following the full guidance of an empirical POD study as given in MIL HDBK1823A. From these assessments, a relationship can be developed between the response from EDM notches and the fatigue cracks. Depending on the NDI technique being used, the relationship can be linear, but caution must be taken to ensure all factors that affect the location of the defect in the actual structure, such as surface residual stresses, are included in developing this relationship.

Once this relationship is established, it is possible to prepare a set of test samples of the representative geometry and materials, plus insert artificial defects, such as EDM notches. Another set of empirical measurements generates the POD curve for the geometry of interest and then the numerical relationship developed from testing a simple geometry can be applied to obtain the POD curve for the grown defects, such as fatigue cracks. This approach has been used by the USAF to determine the POD for a very complex geometry [4]. The pay-off from this approach is the ability to generate a POD curve without having to grow defects in a complex geometry which can become very time consuming and quite expensive. A significant word of caution must be repeated, namely the simple test samples must be prepared to have all the attributes of the real component. As an example, compressive surface residual stresses can cause fatigue cracks to close and greatly decrease the sensitivity of ultrasonic inspections. Therefore, transfer functions for techniques that are affected by such parameters in the component of interest must be approached with a great deal of caution. Appropriate “knock-down” factors must be specified to account for the changes between the simplified geometry and the conditions of the component of interest.

3.2 Full Model-assisted POD

With the full model-assisted approach to determine a POD curve, the capability of inspection simulations, whether they be numerical or analytical models, are leveraged to decrease the number of test samples required to complete an empirical POD study. These approaches depend heavily on the validated capability of the simulation and, therefore, have not made significant inroads to being used for the assessment of production-based inspections. The frame work to address this capability has been defined [5] as part of the effort of the MAPOD Working Group.

A critical aspect of the simulation methodology is that it must address all the parameters that affect the inspection process. This includes variations in the defects (i.e. the model cannot assume a fatigue crack has non-connected surfaces), the component of interest (i.e. local boundary condition variations), and the inspection method (i.e. proper sensitivity calibration processes). These variables, which can easily number into the 10s and 20s [6], make the use of models challenging as they need to address the variability of all relevant parameters and how they affect the sensitivity of the inspection method. The rigorous process for model validation can offset the cost and time savings that could be realized by not generating test samples for an empirical assessment, making this option much more challenging and not as mature in its use.

4. MAPOD WORKING GROUP

The MAPOD Working Group was established in 2004 by AFRL in cooperation with the FAA and NASA. The MAPOD Working Group had as its goal the promotion of the increased understanding, development and implementation of MAPOD methodologies. Participation in the working group was voluntary. It met at least annually periodically for over 10 years, with most meetings held in association with major technical conferences to encourage as much participation as possible. At its peak, the working group included almost 100 contributors from industry, national laboratories, and academia. Minutes and copies of many of the presentations used to be hosted on a public website, but recent changes in policy, unfortunately, resulted in much of this information being removed. However, an excellent summary has been published on the overall objectives of the Working Group can be found here [5]. With recent increased interest in the area of MAPOD, there is motivation to rejuvenate the Working Group to address emerging POD challenges, such as those found in structural health monitoring. One of the significant accomplishments of the Working Group was to reach consensus and publish a framework for the full-model assisted POD study. Considerations for MAPOD as addressed by the Working Group were included in an appendix of MIL HDBK 1823A [3].

5. SUMMARY

This introduction to MAPOD highlights efforts to develop methods to simplify the determination of PODs over recent decades. The need for POD studies are critical to enable risk management of critical structures, such as USAF aircraft structures as defined in MIL STD 1530Dc1. The importance of POD and the proper design and execution of a POD study led to the publication of MIL HDBK 1823A which provides details on the processes and analysis methods used to execute a POD study and generate POD curves. The time and cost to perform empirical studies led to the exploration of models, through either transfer functions or physics-based models, to ease the burden of generating test samples required for a proper POD study. The use of transfer functions has been implemented for a limited number of inspections by the USAF, but full-model assisted studies are much more constrained. A hurdle for full model assisted studies is the need for fully validated simulation tools that incorporate all the variables found in a typical inspection scenario. The MAPOD Working Group was established in 2004 to share experiences and lessons learned but become less active after about 10 years due to financial and time constraints. However, recent activities in new inspection methods has led to a renewed interest in MAPOD and could rejuvenate the activities of the Working Group.

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