MINUTES
MODEL-ASSISTED POD WORKING GROUP MEETING
SEPTEMBER 23-24, 2004
ALBUQUERQUE, NEW MEXICO

Attendees:

A list of attendees may be found in file 1.

Agenda:

The meeting agenda may be found in file 2.

Minutes:

This one day meeting, conducted from noon on Thursday until noon on Friday, essentially consisted of two parts. On Thursday afternoon, a number of presentations were made, providing agency perspective, background information, and examples of some recently conducted studies. In addition, there was a group discussion and adoption of the prospectus for the Model-Assisted POD (MAPOD) Working Group (WG). On Friday morning, the group conducted broad discussions of a number of technical issues related to establishing protocols for MAPOD and established next steps.

These minutes represent the author's (R. B. Thompson) efforts to capture the essence of the presentations and technical discussions. Extensive reference is made to the PowerPoint presentations from the meeting, graciously made available by the authors.

<u>Thursday, September 23</u>

Agency Perspective: Knopp, Winfree, and Broz, presented their visions of the need for new tools and procedures to conduct model-assisted POD studies. Copies of their transparencies can be found in files 3-5.

Background: Thompson summarized the background for the meeting, including the steps that led to the formation of the MAPOD WG, the plan for the current meeting, and some general technical observations. Copies of his presentation may be found in file 6.

Case Study of a Demonstration: Smith presented a summary of an industrial program in which MAPOD techniques had been applied to assessing the POD of ultrasonic inspection of aircraft engine rotating components. To the author's knowledge, this is the first full demonstration of this approach in an industrial environment.
Slides from his presentation may be found in file 7.

Discussion of Calibration Issues: The relative merits of three-point as opposed to one-point calibration have been a subject of active discussion in the POD community in recent months. Rummel presented a discussion of the factors motivating the need for three-point calibration and Nakagawa discussed recent, model-based calculations that provide insight into such matters as the best choice of the samples required in the eddy current case. Those presentations may be found in files 8 and 9.

Important Perspectives: There were extended discussions after each presentation. Many of the topics were specific to each presentation and were not recorded in detail. Among the more general comments were the following:

- Protocols will be needed to guide MAPOD demonstrations, and these will be different from those needed to guide empirical POD studies.
- We should add to the global drivers (Thompson slide 15) the need to communicate requirements, e.g. with respect to type, size, orientation, shape and nearest neighbor.
- We must be sure that the end product is acceptable to the structures/risk analysis groups.
- Inspection opportunities, often defined by maintenance intervals, are discrete and limited. Demonstrating improved POD would be particularly beneficial from an economic perspective if it enabled inspections to be avoided at certain maintenance periods or an inspection interval extended to match a maintenance schedule.
- If we are to do literature searches, we must very carefully identify what we are looking for.
- It was asked whether non-aerospace applications are of interest. The general essence of the discussion was that such applications would be of interest. Funded programs in non-aerospace applications are not likely to be established by the particular government agencies supporting the MAPOD WG. However, cross-fertilization with work in other areas is highly desirable. Strategies that would help MAPOD approach gain acceptance are needed and input from other industries, particularly methodologies used and their validation, would help.

Prospectus: A draft prospectus had been sent to the members of the MAPOD WG before the meeting, and it had been briefly reviewed during Thompson's presentation (slides 5-10). A period was set aside for the group to discuss the prospectus. Two important points emerged.

- The statement in the draft prospectus that the MAPOD WG was an unfunded activity led to confusion. Clarifying comments were made to the effect that funded programs could be anticipated in this area. The work of the MAPOD WG, to provide perspective and general discussion, is unfunded. However, it is anticipated that funded programs will develop to conduct some of the work that is identified as being needed.
- A question was raised regarding how the results of the various meetings of the MAPOD WG would be communicated. It was noted that this is particularly important in a volunteer activity, since many people will not be able to attend all meeting. Thompson said that CNDE would establish a web-site to handle this problem.
    - It was suggested that this should include sections to identify who is working on what areas.

   - It was also suggested that this include reference to the NTIAC report as well as the proceedings of the Austin meeting.

With the understanding that these ideas would be incorporated in the prospectus, the group adopted by consensus the draft. The final prospectus may be found in file 10.

<u>Friday, September 24</u>

This was a day of open discussion about strategies, demonstrations and future directions. A major part focused on better conceptualizing what would be involved in a protocol for MAPOD determination, a need that was strongly identified throughout the previous day. The attendees came from a quite varied background, including statisticians, physicists, and engineers, some of them having considerable experience in the field practice of NDE. Not surprisingly, the discussions were free flowing and often moved from topic to topic as the group developed its understanding of the key issues, how they were interrelated, and how they should be addressed. No attempt was made to develop a sequential transcript of that discussion for these minutes. However, the following sections summarize the major outcomes, not necessarily in the order that they were developed.

General Issues: Thompson noted that, in developing a MAPOD protocol, there are a number of questions that must be addressed including the following.

- What elements are required (bases that need to be touched)?
- How prescriptive should the protocol be?
- How do we test to be sure that a protocol is not overly prescriptive and is robust in typical situations?

After an extended discussion related to these issues, Aldrin noted that a way to organize the thoughts of the WG on these matters would be to consider three broad issues.

- Broad Scope-What should be addressed in a protocol
- Details of Methodologies-Clarification of the steps required to make a MAPOD determination
- Process Issues-Developing definitions of the toolbox that would be needed and how it would be used

After considering the possibility of discussing these separately in break-out groups, the majority of the WG decided that they wanted to be a part of the discussion of each and decided to address these topics serially.

Scope: Smith led a discussion of scope. He noted that there were three possible methodologies that should be considered.

- 1823-This was motivated by the technique(s) developed by Berens, Hovey and others. These are mostly empirical but do use statistical models having to do with the functional form of the distribution relating flaw size and flaw response.
- Transfer Function (XFN) Approaches-This is an approach in which physics-based understanding is used to extend the results of one POD study to another, similar situation

- Full Model-Assisted (FMA) Approaches-This is an approach along the lines presented at the conclusion of Thompson's talk (slide 30) and demonstrated in an industrial problem by Smith

As a straw man, Smith asked if the group wished to define its scope as developing a protocol that would include all three of the above approaches, along with a set of procedures that would determine under which conditions each would be used. Figure 1 schematically shows how that might be laid out.

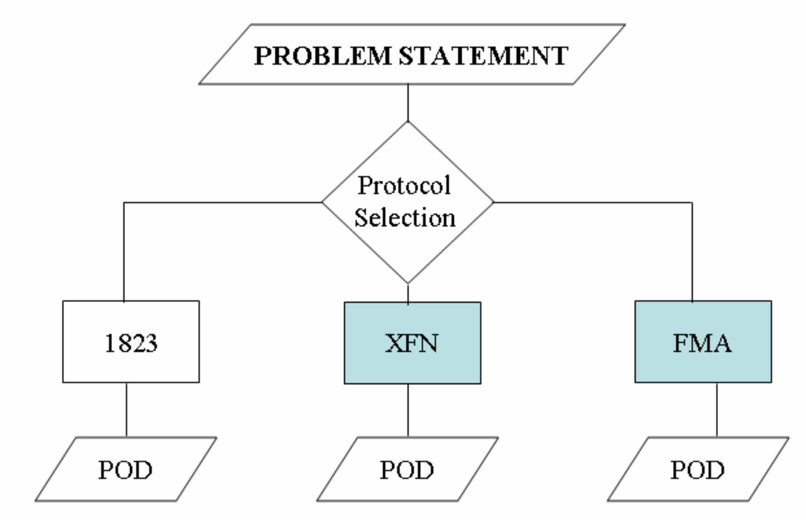

Figure 1-Schematic of an overarching protocol that would include multiple, MAPOD approaches.

The WG decided that developing an overarching protocol, as illustrated in Figure 1, was too big of a task to undertake at the present time and decided that it would be better to separately, and in parallel to consider the Transfer Function (XFN) and Full Model-Assisted (FMA) approaches (highlighted in Figure 1). It was agreed that fairly generic approaches would be most appropriate so that flexibility would be retained. The group decided that the objective would be the following.

Objective: To codify methods which are less cost/time intensive than 1823

Strategies to address this objective were discussed. It was suggested that a short run strategy might be to demonstrate the XFN approach on a classical problem, e.g. the detection of cracks under fasteners, leading to a protocol. A longer run strategy would be the development of protocols for the FMA approach. It was suggested that a lot of early experimentation might be required in these early demonstrations.

Note that the Figure 1 is schematic in that various elements could be used in conjunction with one another.

Need for an Umbrella Document: As a precursor to the discussion of methodologies, Spencer emphasized the need to establish an umbrella document that is generic with respect to the field of NDE yet comprehensive with respect to issues that need to be addressed in the development of MAPOD quantification. His initial thoughts, found in file 11 which was provided to the group as "read-ahead" material, identified a number of issues including the needs to assess and quantify the confidence in the use of models, integrate simulation and experimental activities, and to develop a common glossary of terms.

To illustrate those thoughts, he discussed a hypothetical situation in which a MAPOD approach was described by a relationship of the form

$$S = f(x_1, x_2, x_3, \ldots, x_n) + \varepsilon \quad (1)$$

Here S is the observed signal, $x_1 \ldots x_n$ are factors that control that signal level, and ε is a random variable that describes variability in signal for fixed x-values, i.e. noise. A nondestructive inspection can be thought of as resulting in a mapping of Equation (1) onto a detection threshold. The form of the POD curve, e.g., its steepness, depends on the variability of the x's as well as the distribution of the noise factor.

As one example of the need for a common glossary, Spencer pointed out that Eq.(1) illustrates two important differences in the way the community thinks about POD. If one wishes to think about the POD of a type of inspection, e.g. eddy current inspection of bolt holes as implemented in response to some specified procedure, then one has to consider each of the factors to be governed by a distribution. In the example given, one such factor would be related to the variability of probes. This variability would contribute to the breadth of the signal distribution for a given flaw size and hence lead to a reduced steepness of the POD curve. This is in contrast to the somewhat steeper POD curve that would be exhibited for fixed values of probe and other factors. Figure 2 schematically illustrates these differences. When POD curves are reported in the literature, it is important to specify to which circumstance they apply. In new situations, the user will have a particular problem to consider in which some of these factors may have fixed values while others may not. It is important to use the POD curve corresponding to the situation of interest. In order to be able to coherently discuss these issues, a common glossary of terms is essential. For example, the community must be able to clearly speak about the variability of the input factors, the accuracy limits of the models, the confidence bounds (or other metrics on expected accuracy) that govern the POD estimates, and what is meant by "human factors". The latter is used in a variety of ways to cover a variety of issues, and a common language is required to ensure that members of the community are communicating accurately. For example, do we think of "human factors" as being fully embedded in the noise factor ε or do we associate some of it with variations in the input parameters, $x_1, x_2, \ldots, x_n$.

Spencer noted that the use of models to replace empirical data is occurring in a variety of fields, including the Department of Energy effort in Scientific Stockpile Stewardship. These other communities have faced many of the same issues being discussed by the MAPOD WG, and we should learn from their experiences.

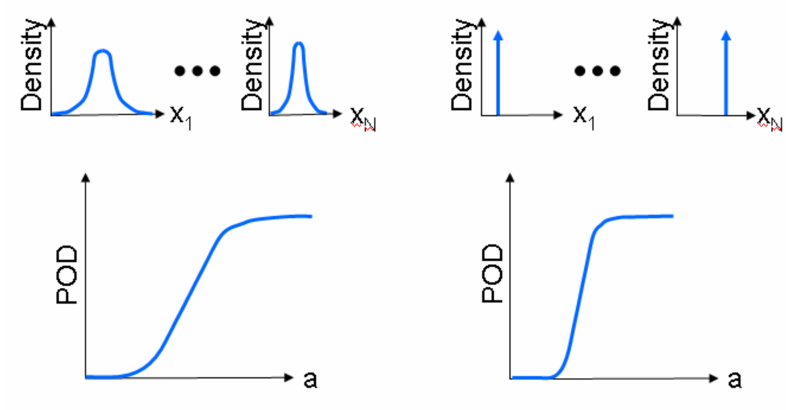

Figure 2. Influence of parameter variations on POD
Left: Distribution of input parameters
Right: Fixed input parameters

A further example of the need for a common glossary of terms arose in the subsequent discussions, summarized below. The NDE community often uses the term "simulation" to refer to a physics-based, deterministic prediction of a signal level. However, in the statistics community, this same term is often used to refer to a Monte-Carlo procedure in which input parameters are randomly varied to examine the distribution of some function depending on them.

FMA Approach: Discussion of a protocol for a FMA POD determination focused on the steps that had been suggested by Thompson in slide 30 of his presentation (file 6), reproduced in Figure 3. Here, the need for a glossary again was evident. Some of the comments made were the following.

- It should be made clear in bullet 1 that "simulation" refers to a physics-based model prediction with appropriate input parameters.
- In bullet 6, explicit steps are required to specify what is meant by "quantify…."
- In bullet 3, more elaboration should be given to the activity required to "verify its accuracy …". For example, one needs to consider the effects of uncertainties in the verification experiment. It was also suggested that this might more appropriately be called "validation".

STEPS TO GENERATE MODEL-ASSISTED POD*

- ☐ Identify controlling factors whose influence can be simulated using a physics based model
- ☐ Develop appropriate model
- ☐ Verify its accuracy in the laboratory through well controlled experiments
- ☐ Determine values of input parameter (or parameter ranges) appropriate to field application)
- ☐ Use simulation tool to predict mean response and those components of variability controlled by well understood physical phenomena
- ☐ Quantify additional sources of variability associated with components of variability not controlled by well understood physical phenomena and with variations of input parameters that cannot be fully controlled in the production environment
- ☐ Compute POD

*Adapted from R. Bruce Thompson, "Using Physical Models of the Testing Process in the Determination of Probability of Detection," Materials Evaluation, 59, pp. 861-865 (2001).

Figure 3. Proposed outline of steps for MAPOD procedure

XFN Approach: Rummel discussed the XFN approach which was in part the motivation for the discussion of three-point calibration that was held on Thursday afternoon. Figure 4 schematically illustrates the basic idea. Consider the determination of POD following the a-hat versus a procedure. The central element is a regression line (and the variance of the data with respect to this line), generally drawn in a log-log coordinate system, relating signal response (taken to be a measure of observed size) to true flaw size. This will be based on data obtained under a specified set of experimental conditions, e.g. eddy current examination of EDM notches in a bolt hole. However, suppose that one wants to apply the POD to a new situation, say the detection of fatigue cracks in a bolt hole of the same material. This would be done if one knew how much the regression line and variance would be shifted by the difference in the responses of fatigue cracks and EDM notches. The fundamental idea of the XFN approach is to estimate that shift and the change in the variance of the data about the regression line with the assistance of physics-based models or the results of well-controlled benchmark experiments.

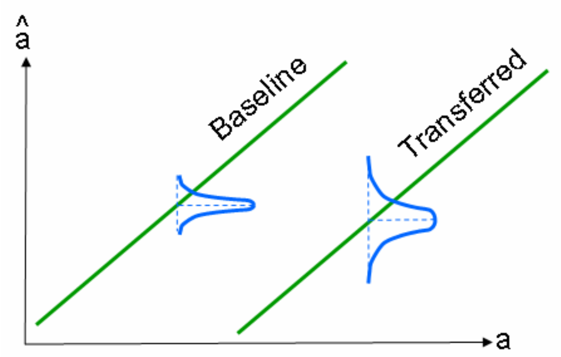

Figure 4

Desired Toolbox: In order to utilize the XFN approach, a "toolbox" is required to provide the basis for predicting the regression line. For example, one might want to have a rational basis for taking into account the effects of changes in probe scanning speed, raster index, component geometry, material and crack type. It was suggested that the toolbox would be a set of pieces of code with inputs related to inspection factors and an outputs related to how signal strength and variance vary with those inputs, information that could be developed either empirically or based on physics-based models. It would be drawn on to implement the XFN protocol, describing the shift in the regression line and changes in variance.

Relation of FMA and XFN Approaches: In discussions it was recognized that the FMA and XFN approaches might ultimately be viewed as parts of a single, unified approach. However, their current conceptual descriptions are somewhat different, with the former being derived from a "top-down" approach and the latter a "bottom-up" approach. It was agree that, for the time being, it would be valuable to pursue these different approaches, with insight to be gained from examining the complementary nature of the views.

Future Demonstrations: Discussions were held regarding problems that would be appropriate topics for future demonstrations. Adopting the criteria that these should be sufficiently generic to have wide spread implications, the following three topics were identified.

- Cracks under fasteners
- Cracks in engines (e.g. bolt hole or dovetail geometries)
- Volumetric defects in engines

It was recognized that there is significant "hard work" to be done in investigating any of these cases, and that this could not be done by a volunteer group and would require a funded program. It was felt that there might be some data available that would be a starting point for the case of cracks in engines, but a significant effort would be required to extract it in an appropriate form from available files. For the case of cracks under fasteners, no appropriate data was known and it was felt that this problem would have to be addressed on a go forward basis. The need to examine volumetric defects in engines is motivated by life extension programs such as ERLE and the desire to reach the technical goal of extension for several lives (the topic of a Special Session 21, 3D POD, organized by Rummel at the Review of Progress in Quantitative Nondestructive Evaluation in July, 2004).

Image-based POD: In preparing for the WG meeting, input had been sought from the attendees for ideas relating to potential demonstrations of the MAPOD approach. Two suggestions had been received, each of which dealt with image-based decisions, i.e. situations in which accept-reject decisions are made on the basis of information present in multiple pixels. Given the fruitful discussions that are reported above and which occupied the full length of the meeting, the group decided to defer discussions of image-based topics until the next meeting. The "read-ahead" materials that had been provided Gray and Shih are included in files 12 and 13.

Action Items: At the conclusion of the meeting, a number of action items were adopted to guide future activities of the MAPOD WG. There were the following.

- Establish a web site: ISU
- Include a reference list and a place where relevant papers could be placed if volunteered: ISU
- Provide an electronic copy of 1823: Spencer→Thompson→WG
- Comment on what elements should be included in a MAPOD protocol: Spencer
- Develop a list of empirical POD studies that have been conducted: I. Gray
- Develop a list of model-based POD studies that have been conducted (NTIAC report provides a good start): Aldrin
- Develop a list of items that should be included in the "Toolbox": Rummel
- Recommend the ultimate repository for the protocols to be developed: Malas
- Scope out how the XFN and FMA approaches could be applied to generic problems of high current interest (cracks under fasteners, cracks in engines, volumetric defects in engines): Malas, Smith, Brasche, Aldrin, Knopp, Thompson

Next Meeting: The next meeting of the MAPOD WG will be held after the Aging Aircraft meeting in Palm Springs California. The Aging Aircraft meeting will be held Monday, January 31-Thursday, February 3. The MAPOD WG will meet on Friday, February 4.

References:

1. J. Amos, J. Gray, A. Lhemery, and R. B. Thompson, "Future Applications of NDE Simulators," Review of Progress in Quantitative Nondestructive Evaluation, Vol. 23B, D. O. Thompson and D. E. Chimenti, Eds. (AIP, NY, 2004), pp. 1620-1632.